SMART EVACUATION PLAN USING AUGMENTED REALITY

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1.0 INTRODUCTION

Augmented reality (AR) is a technology that overlays digital content—such as 3D objects, graphics, and visual cues—onto the user's real-world environment in real time. AR has gained significant attention in fields such as education, tourism, industrial training, and medical simulation due to its ability to enhance spatial awareness and improve user engagement (Billinghurst, Clark, & Lee, 2015). However, its application in emergency evacuation remains underdeveloped, especially in scenarios where internet access or power supply is disrupted.

In critical emergencies like fires or blackouts, conventional evacuation tools such as static signage or cloud-based navigation systems may become ineffective. Many existing systems rely on real-time data from IoT devices or online services, which are vulnerable to failure during disaster events (Singh, Gupta, & Verma, 2021). Therefore, this project addresses the urgent need for a self-contained, offline AR evacuation system that can function independently without external networks or infrastructure.

This system presents an interactive mobile AR application that visually guides users to safety through predefined evacuation routes. The application overlays 3D directional arrows and interface elements onto the user's environment, enabling intuitive decision-making in high-stress conditions. Unlike many AR solutions that use AR Foundation or cloud-based content, this project adopts a fully offline approach. The 3D environment of the building was modeled using Autodesk 3ds Max and integrated into Unity, allowing for a customized and realistic indoor navigation experience tailored to specific spatial layouts.

Users can control the camera view using their device's gyroscope, while functional UI elements—including a danger button to switch escape routes and an instruction panel—assist with navigation. The system supports multiple rooms and route-switching logic, making it suitable for deployment in environments such as dormitories, offices, classrooms, and public facilities. By combining 3D modeling, gyroscopic input, and preloaded AR overlays, this project contributes to a more resilient and accessible evacuation solution, free from infrastructure dependency and suitable for real-world implementation (Lee & Kim, 2021; Lovreglio & Kinateder, 2020).

2.0 LITERATURE REVIEW

Numerous studies have explored the application of augmented reality (AR) in indoor navigation and emergency evacuation, highlighting both its potential and limitations. Azuma's foundational definition of AR emphasized its ability to superimpose digital content onto the real-world environment to support user interaction and decision-making. Chen et al. (2020) demonstrated that AR evacuation guidance systems using algorithms like Dijkstra's can significantly reduce confusion and improve route clarity in indoor emergencies.

Billinghurst, Clark, and Lee (2015) provided a comprehensive survey on AR systems and emphasized their effectiveness for indoor navigation, especially in environments with limited visibility or signage. Their findings were supported by Lee and Kim (2021), who showed that Unity-based AR applications with multi-level navigation capabilities improved user orientation and evacuation outcomes in complex buildings.

Other researchers, such as Lovreglio and Kinateder (2020), focused on user psychology during evacuations, highlighting the importance of visual clarity and simplicity under high stress. Ingole et al. (2024) further emphasized AR's capability to reduce cognitive load through direct overlay of escape cues in indoor navigation systems.

Contrastingly, Singh et al. (2021) and Green (2021) explored the integration of AR with IoT and sensor networks, enabling real-time adaptive evacuation planning. However, such systems depend on stable infrastructure, which may not be available in emergencies. To address this, Kang et al. (2018) proposed QR-based indoor guidance, which works offline but lacks flexibility and requires physical markers.

The Smart Evacuation Plan developed in this project adopts a static AR model with predefined navigation paths. Users interact through room buttons to trigger route display, and a danger button allows switching to alternative paths. This approach aligns with findings from Zhang et al. (2019) and Smith (2022), who argued for scalable, markerless, and stress-resilient evacuation solutions. It also supports the UKM guideline on technical simplicity and offline accessibility (Universiti Kebangsaan Malaysia, 2023).

In conclusion, the proposed system combines the reliability of static AR overlays with manual user control, bridging the research gap in offline-capable emergency navigation. It emphasizes user clarity, system resilience, and adaptability without reliance on external sensors or connectivity.

3.0 METHODOLOGY

The development of the Smart Evacuation Plan Using AR followed a structured and iterative approach, consisting of four main phases: requirement analysis, system design, implementation, and testing. This methodology ensured that both technical feasibility and user expectations were addressed throughout the development lifecycle.

3.1 Requirement Analysis

To define clear objectives for the system, preliminary investigations were carried out by observing user behavior in simulated evacuation scenarios and consulting building safety guidelines. User interviews and secondary research helped to extract key pain points in existing emergency procedures.

The key requirements derived were:

- The system must work entirely offline, with no reliance on real-time network connectivity or sensor infrastructure.
- Evacuation paths must be visualized clearly in the user's physical environment using digital overlays.
- A mechanism must be available to allow users to switch from the main path to an alternate escape route if the original is blocked.
- The camera view should be controlled using natural device movement (gyroscope), without needing touch input.
- Instructional support must be provided through toggleable UI elements for first-time users.
- The system should allow easy scalability to support multi-room building environments.

These requirements laid the foundation for a modular and highly adaptable evacuation assistance system.

3.2 System Architecture and Tools

The system architecture was designed using a component-based paradigm and consists of three main technical layers: 3D modeling, AR interaction logic, and user interface control.

3D Modeling:
Floor plans and interior layouts were manually created using Autodesk 3ds Max based on sample building structures. These models included walls, doors, and corridor layouts, which were exported into Unity in FBX format. Line paths representing escape routes were embedded in 3D space, allowing for precise positioning of visual arrows in Unity.

1. **AR and Navigation Logic**:
   Unity (2022.3 LTS) served as the development platform. Since AR Foundation was not used, the AR experience was simulated by aligning the main camera to a user's gyroscope and anchoring escape arrows to fixed positions within the virtual scene. The LineRenderer component was used to create directional path lines, while gyroscopic input allowed users to control view direction by simply rotating the device.

2. **User Interaction and UI Management**:
   The system features multiple interactive elements:

   - A **"danger button"** allows users to switch between main and alternate evacuation paths. When activated, the existing path deactivates and the alternate path is displayed in real time.
   - An **instruction panel** provides on-screen guidance and can be toggled for user reference.
   - **Room detection logic** ensures that only relevant escape paths are displayed for the active room environment. Each room has its own script controlling the path and panel behavior.

The architecture emphasizes simplicity, speed, and robustness in emergency situations where user stress and time pressure are critical.

3.3 Development Environment

- **Game Engine**: Unity 2022.3 LTS
- **3D Modeling Software**: Autodesk 3ds Max
- **Target Platform**: Android (tested on Xiaomi 14 Pro)
- **Scripting Language**: C#
- **AR Rendering**: Unity Camera + LineRenderer (without ARKit/ARCore)
- **Control Mechanism**: Gyroscope-based rotation (SystemInfo.gyroscope)
- **Scene Management**: Manual loading and toggling between room objects

The modular structure of the project facilitated easy debugging and testing of each feature independently before integration.

3.4 Key Functional Modules Implemented

Table 1: Test traceability matrix

Function ID	Description
F001	AR evacuation path visualization using LineRenderer
F002	User interaction with danger button
F003	Switch between main and alternate paths
F004	Gyroscope-based direction control for camera
F005	Open/Close instruction panel via UI
F006	Display escape direction arrows dynamically
F007	Room detection and contextual logic handling
F008	UI reset, toggle, and fail-safe behavior

Each module was developed as a C# script component in Unity, using Nonbehavioral lifecycle methods and UI system libraries.

3.5 Implementation Strategy

The system was implemented using an incremental prototyping model. Initial testing was conducted with a single room and one main path. Once stable rendering and camera rotation were confirmed, alternate paths and UI interaction layers were added. Room switching logic was added last to simulate a realistic multi-room evacuation scenario.

To ensure high system availability in emergency conditions, all assets—including 3D models, scripts, and UI prefabs—were embedded in the local build. No external data or cloud service was used. Frequent play-mode testing on real Android devices helped evaluate gyroscope responsiveness, lighting clarity, and user comfort in holding and rotating the device.

4.0 RESULTS

The Smart Evacuation Plan Using AR was evaluated through two primary approaches: functional testing of system features and user satisfaction assessment based on real-user feedback. The goal was to determine whether the application meets technical expectations and provides a user-friendly experience during simulated emergency scenarios.

4.1 Functional Testing

All eight key functional modules were tested in a controlled environment using an Android mobile device. The tests included individual validation of each feature such as:

- **F001**: AR evacuation path visualization rendered correctly in each room.

- **F002 & F003**: The danger button accurately triggered switching between main and alternate routes.
- **F004**: Gyroscope-based direction control was smooth and matched device orientation.
- **F005**: The instruction panel opened and closed correctly, enhancing usability.
- **F006**: Escape arrows were displayed clearly, even when switching rooms or changing directions.
- **F007**: Room logic was successfully detected, displaying the appropriate evacuation path per room.
- **F008**: UI reset and toggle buttons responded as intended, with no freezing or conflict across multiple inputs.

All functional tests passed without runtime errors. The system responded consistently across multiple testing sessions and room layouts. Figure 4.1 shows the evacuation path with directional arrows in AR view, while Figure 4.2 illustrates the path switching activated by the danger button.

4.2 User Satisfaction Evaluation

To validate user experience, a total of 15 volunteers—comprising students, staff, and safety personnel—were asked to use the application in a guided test session. After interacting with the system, participants completed a satisfaction questionnaire containing Likert-scale items (1 = strongly disagree, 5 = strongly agree) covering the following aspects:

- Ease of use
- Visual clarity
- System responsiveness
- Usefulness in emergencies
- Satisfaction with offline performance

The average satisfaction score across all items was **4.6 out of 5**, indicating high overall acceptance of the system. The most positively rated aspects were the offline capability and clarity of the escape direction arrows.

Some qualitative feedback from users included:

- “Very easy to understand, even under stress.”
- “The danger button is useful in showing options.”

- “It works without internet, which is essential during power failures.”

A few users recommended adding voice instructions or multilingual support to improve accessibility for non-English speakers.

4.3 Summary of Findings

Table 1: Tested Functions

Evaluation Category	**Result**
Path Visualization	Clear, accurate, and immersive
Danger Button Switching	Immediate response, no lag
Gyroscope Control	Smooth and intuitive
UI Panels	Easy to toggle, helpful for guidance
Offline Performance	Fully functional without connectivity
Overall User Satisfaction	4.6 / 5

The results demonstrate that the system meets its design goals of providing a simple, reliable, and intuitive AR-based evacuation guidance tool that functions entirely offline.

5.0 CONCLUSION AND FUTURE WORK

5.1 Conclusion

This project successfully developed and evaluated a Smart Evacuation Plan Using Augmented Reality that operates fully offline. The system was designed to assist users during indoor emergencies by providing clear, immersive, and preconfigured evacuation routes that do not rely on internet connectivity or external sensors.

By using Unity and 3ds Max, the system incorporated room-specific AR overlays, gyroscope-based camera control, a danger button for route switching, and an instructional user interface. Functional testing confirmed the stability and effectiveness of each feature, while user satisfaction testing indicated high approval ratings, particularly for the system’s simplicity, visual clarity, and offline reliability.

The implementation demonstrates that even without advanced real-time technologies such as ARKit or cloud-based systems, a static AR framework can still provide valuable emergency navigation support. This makes the system particularly suitable for buildings where infrastructure is limited or unstable during disasters.

5.2 Future Work

While the current version of the system is stable and functional, several enhancements can be considered to improve scalability and user experience:

- **Audio Guidance**: Adding voice instructions can support users in noisy or low-visibility environments.
- **Multilingual Support**: Localizing the UI and instruction panels can improve accessibility for diverse communities.
- **Dynamic Obstacle Detection**: Although the current system is static, future versions could integrate optional sensor input or QR-based updates for real-time path adjustment.
- **3D Navigation Enhancements**: Elevators, staircases, and multiple building levels can be modeled for complex navigation scenarios.
- **Gamified Training Mode**: Introducing a practice mode with scenarios and performance feedback can help users learn evacuation procedures before actual emergencies occur.

Overall, the project has laid a strong foundation for an accessible and deployable AR-based evacuation system. With further refinement, it has the potential to be adopted in public institutions, residential facilities, and workplaces to enhance disaster preparedness and response.

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