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A Mobile Augmented Reality Application for Indoor Emergency Evacuation and Navigation

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Abstract

During emergencies, accurate and timely dissemination of evacuation information plays a critical role in saving lives and minimizing damage. As technology continues to advance, there is an increasing need to explore innovative approaches that enhance emergency evacuation and navigation in an indoor environment to facilitate efficient decision-making. This paper presents a mobile augmented reality application (MARA) for indoor emergency evacuation and navigation in a building environment in real time. The location of the user is determined by the device camera and translated to a position within a Digital Twin of the Building. AI-generated navigation meshes and augmented reality foundation image tracking technology are used for localization. Through the visualization of integrated geographic information systems and real-time data analysis, the proposed MARA provides the current location of the person, the number of exits, and user-specific personalized evacuation routes. The MARA can also be used for acquiring spatial analysis, situational awareness, and visual communication. In emergencies such as fire and smoke visibility becomes poor inside the building. The proposed MARA provides information to support effective decision-making for both building occupants and emergency responders during emergencies.

1. Introduction

Over the past several decades, there has been an increasing interest in the field of Virtual reality (VR) and Augmented Reality (AR) technology. VR immerses users in virtual environments, allowing them to interact with people, objects, and interfaces. On the other hand, AR overlays virtual elements onto existing physical environments for integrated experiences. The entertainment and construction industries have found creative applications for this technology. In the context of emergency response, Mobile Augmented Reality (MARA) can quickly guide users to safety through complex buildings. AR solutions can convert static blueprints of building floor plans into dynamic, interactive models, allowing users to visualize and manipulate designs, structures, and data directly in the environment. MARA has the potential to revolutionize everyday spaces by transforming buildings into immersive areas, where users can interact with virtual elements in real time. Sharma et al. [1-8] have developed mobile AR applications for building evacuation and for acquiring spatial analysis, situational awareness, and visual communication. They have incorporated permanent features in the building such as room signs as markers for localization to display the floor plan of the building and show navigational directions to the exit. Their work shows how MARA can be used for situational awareness in multilevel buildings during evacuations.

Federal and local laws require facilities to post emergency action plans (EOP) that include evacuation routes, firefighting instructions, and standard safety procedures. Building safety administrators typically post evacuation plans near doorways, elevators, and restrooms. In unfamiliar buildings, occupants must refer to signage to determine the most effective escape route. Occupants must quickly memorize directions and identify the appropriate building landmarks to match as they navigate. In the event of blocked passageways or exits, occupants must search for alternative routes to safety. As a result, these emergency action plans have major limitations in larger facilities. MARA presents an opportunity to address some of these issues.

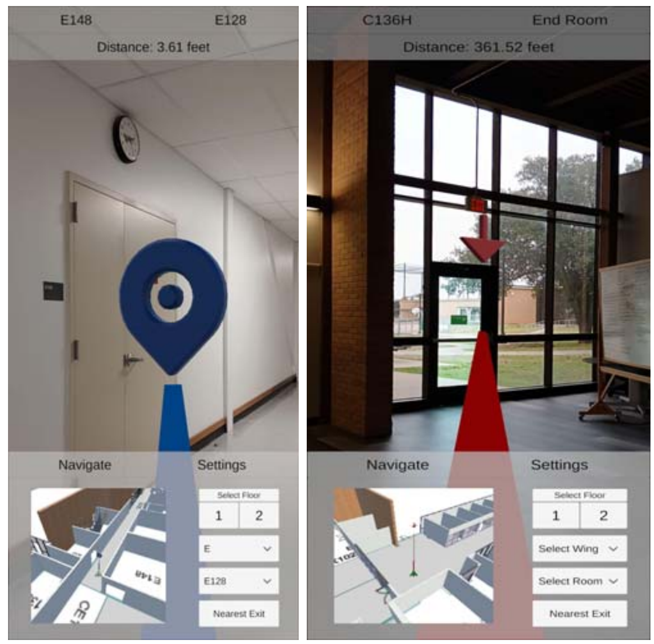

Figure 1. MARA shows the navigational route in real-time and a digital twin of the building.

This paper proposes MARA, a solution for real-time indoor navigation and evacuation using digital twin technology by promoting user spatial awareness and improving understanding of emergency evacuation procedures. It overlays 3D models onto the users' mobile device (smartphone or tablet) that serve as a visual navigation guide to the desired location. Through device tracking, the MARA provides real-time location updates that reflect the user's movement throughout the building. Additionally, the MARA continuously updates routes in response to user behavior, reducing the reliance on stationary and static signage. This immersive and interactive experience allows for increased awareness for building occupants by showing navigation routes in real-time as shown in Figure 1. These features provide practical benefits that can enhance the navigation experience and aid in emergency evacuation scenarios.

The rest of the paper is structured as follows. Section 2 briefly describes the work done previously. Section 3 describes the system architecture of the proposed mobile augmented reality application. Section 4 describes the implementation of the mobile augmented reality application in four phases. Section 5 lists the conclusion and future work.

2. Related Work

AR applications have been used for a blind user interface to perceive the physical constraints of the real world using haptic and voice augmentation. Jodeph et al. [9] have developed an indoor navigation with a blind user-oriented AR. Their travel route uses voice guidance, which is achieved by extracting the landmarks and is based on landmark localization. Lorenz et al [10] have proposed a navigation model for representing nodes (rooms and corridors) and edges (doors). Their navigational model uses access points to reach different floors from interface nodes, provided by a graph hierarchy algorithm [10]. Brock et al [11] have designed an interactive map prototype for visually impaired people. The interactive map is placed on a multi-touch screen which provides audio feedback of the map associated with touch screen technology. Fallah et al [12, 13] have proposed Navatar which includes building maps and manual preprocessing to annotate landmarks required for navigation.

Indoor navigation systems for the visually impaired have been developed that augment the physical infrastructure with identifiers such as RFID tags [14–16]. It becomes challenging and expensive to have a large amount of RFID tags to cover a whole building. Other solutions for indoor localization aids for the visually impaired have also been employed using laser sensors [17], [18] or cameras [19]. Indoor wayfinding has also been presented for using autonomous robots and a network of Radio Frequency Identification (RFID) tags [20-22]. One of the limitations of this approach is a restriction to places that a mobile robot can reach.

3. System Architecture of MARA

Figure 1 illustrates the system architecture for the proposed MARA. Using the device camera, the user scans the nearest room marker to establish their initial location. The device can either be a phone, tablet, or VR headset The camera continues scanning for room marker until it finds the matching image. The devices contain an accelerometer and gyroscope that begins tracking the user's movement. The Inertial Measurement Unit (IMU) records these measurements and translates them into Unity units.

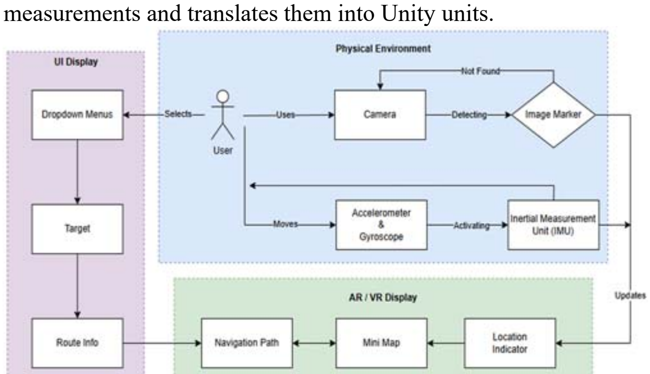

Figure 2. System Architecture for the indoor navigation MARA.

The camera and IMU components work together to update the user's location indicator in the Mini Map which reflects the 3D virtual environment. The user then interacts with the interface via buttons and dropdown menus. The user selects the appropriate floor, wing letter, and room number of their desired location. Alternatively, the user can choose to find the nearest building exit. Based on their input, the system designates a target as the end destination and displays appropriate route information to the user. The MARA generates the navigation path in both the virtual and physical environment.

3.1. Software

Unity gaming engine was used to develop the applications for Android, iOS, and VR/AR devices. AR Foundation is a package within Unity that was also incorporated to provide tools for creating AR experiences. The AR Foundation package works in tandem with systems such as ARCore for Android, ARKit for iOS, Magic Leap XR Plugin, and OpenXR Plugin for AR game development across multiple platforms and devices. AR Foundation is a wrapper framework that manages AR functionality and deploys standardized code to interact with APIs from ARCore and ARKit. Figure 3. shows the relationship between the software modules.

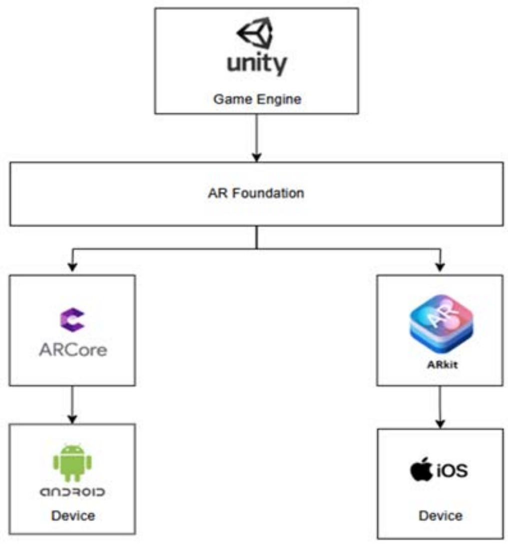

Figure 3. AR Foundation package allows for multi-platform development.

AI Navigation is a package in Unity that facilitates wayfinding for characters and objects. It automatically analyses the scene areas and creates a series of polygons that link together as a surface. This surface provides boundaries wherein the path between two locations must lie. For MARA, the 3D model and underlying floor plan of the building served as a reference to help users navigate around walls, permanent fixtures, and other potential obstacles. Specific areas of the building require specialized access and certain rooms tend to remain locked.

Figure 4. AI Navigation defines walkways and path boundaries around walls

The MARA accounts for this information to direct users around these locations, reduce route complexity, and encourage the use of main hallways where possible. The navigation system does not rely on GPS for location tracking but instead utilizes information based on building specifications. Figure 4 shows the result of the walkable area generated by the AI Navigation tool. The blue surface areas function as a guide for indoor navigation to calculate realistic paths according to the building layout and effectively direct the users to their desired location.

3.2. Hardware

Android mobile devices are the targeted publishing medium for the MARA because they are highly portable in emergency scenarios and readily available for users. Compatibility with AR Foundation and ARCore allows for the device camera to augment virtual 3D models into the real world and track movement. The mobile application was tested and deployed using a Samsung Galaxy A15 and Samsung Galaxy S22. The devices operate on Android 14 with a main rear camera of fifty megapixels, 4GB of RAM, an 8-core CPU, and a 1080x2340 pixel display. These features made the device compatible with Google ARCore requirements and allowed for AR development. The MARA was additionally tested on a Samsung Galaxy Tablet prompting a flexible and responsive UI design.

Iterative testing and development using mobile devices paved the way for deployment to VR/AR headsets. The Meta Quest Pro features five cameras, 12GB of RAM, an 8-core CPU, and an 1800x1920 pixel display per eye, making it a powerful device to publish on. These components allow for a mixed reality experience, where the user can see both the real world and augmented digital elements. Additionally, the two self-tracking controllers contain three cameras for motion detection. The controllers are set up to enable interactions with a floating control panel that mimics the mobile app UI. Simultaneous Localization and Mapping (SLAM) algorithms in combination with the devices' built-in Inertial Measurement Unit (IMU) enabled real-time location tracking. The camera provided additional features such as light estimation, depth understanding, and motion detection to track the user's position and orientation. These components worked together to pinpoint user location and visually guide users through the environment.

4. Graphical User Interface (GUI) for Mobile Augmented Reality Application (MARA)

Figures 5 and 6 show the different states of the MARA GUI, including the navigate and settings panel. The UI serves as a clickable prototype, designed primarily for functionality. Figure 5 shows the full app UI with the navigate panel in the active state. This panel is active on initialization and includes three buttons and two dropdown menus that allow the user to interact with the navigation system. Figure 6 shows the full app UI with the settings panel in the active state. This panel is not active on initialization but includes options for customizing the user experience. The following section explains the individual elements of the UI.

4.1. Mini Map

Figure 7 shows the Mini Map that is based on a 3D model of the building and overlaid on a floor plan. The map shows room numbers, physical materials, and points of interest. The map depicts a top-down view of the user's location within the context of the surrounding area. The third-person view follows the user's movement, including position and rotation. The green arrow indicator represents the user's orientation. The user's current location and remaining path update in the mini map as the user navigates the building. The app displays the map throughout the runtime in the lower third of the screen and intends to help users preview and anticipate their next turn. Users can not directly interact with this feature; however, future work may allow the user to pan the camera view, adjust the angle, and zoom into specific locations.

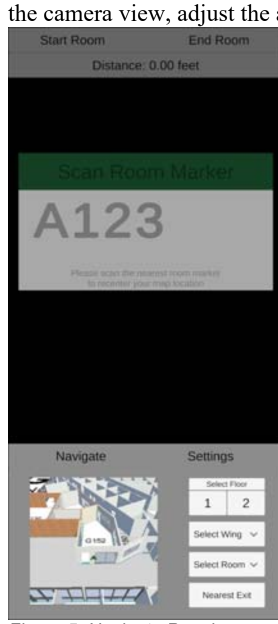

Figure 5. Navigate Panel

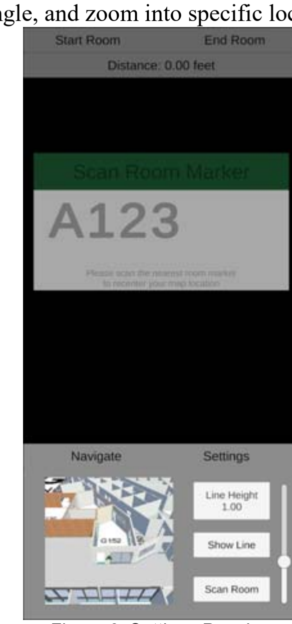

Figure 6. Settings Panel

4.2. Navigate Panel

Figure 7 shows the Navigate Panel, a critical element of the MARA UI. The interface allows the user to interact with both the virtual and augmented environment. To navigate to a specific location, users must select floor, wing, and room number options from a series of buttons and dropdown menus in the user interface. Options for the user dynamically update based on previous selections. If the user selects "1" for the floor number, options will include only the wings and rooms located on the first floor. This selection generates a route for the user to follow from one location to the next. Alternatively, users can select the "Nearest Exit" button to assist in their evacuation. From the collection of stored exit locations, a Unity script calculates the distance between the user's current location and the possible exits. The app displays the exit with the shortest route to the user. A continuous loop ensures accurate and updated evacuation information. Users can click the button again to hide the displayed route.

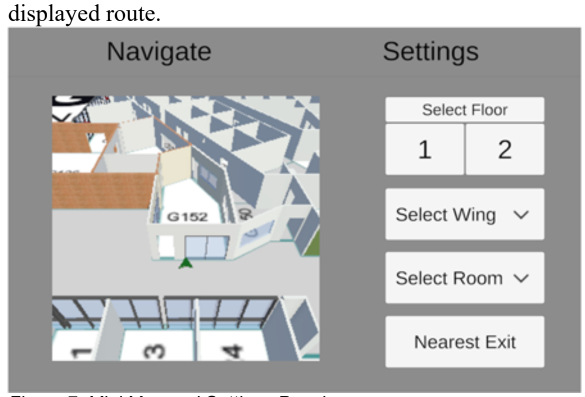

Figure 7. Mini Map and Settings Panel

4.3. Settings Panel

Figure 8 shows the Settings Panel, an integral tool for customizing the MARA app for different users. These features allow the user to access different states of the app and set accessibility preferences.

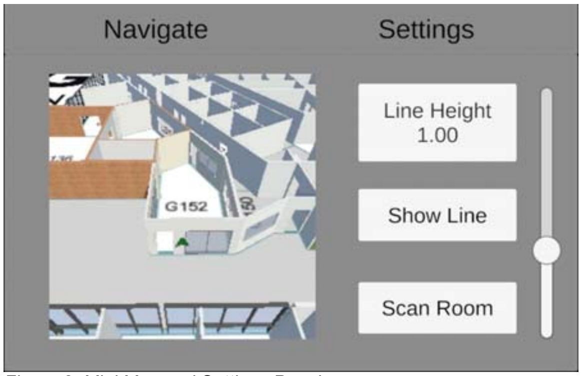

Figure 8. Mini Map and Settings Panel

The panel features a slider on the far right of the interface and a corresponding display in the "Line Height" box. In the mobile application, users employ touch input to adjust this value. In the VR version, users employ Meta Quest controllers to adjust the value. This slider adjusts the height of the displayed route (referred to as the line in figure 8). This functionality increases accessibility for users at various eye-level heights. The route display should not interfere with the user's ability to see the physical environment, but instead, seamlessly integrate into the user's surroundings.

4.4. Route Information

Figure 8 shows the route information is displayed to the user at the top of the UI. The top right corner displays the end location next to the last scanned location on the top left corner. The calculated distance between the user's current location and the desired destination is beneath.

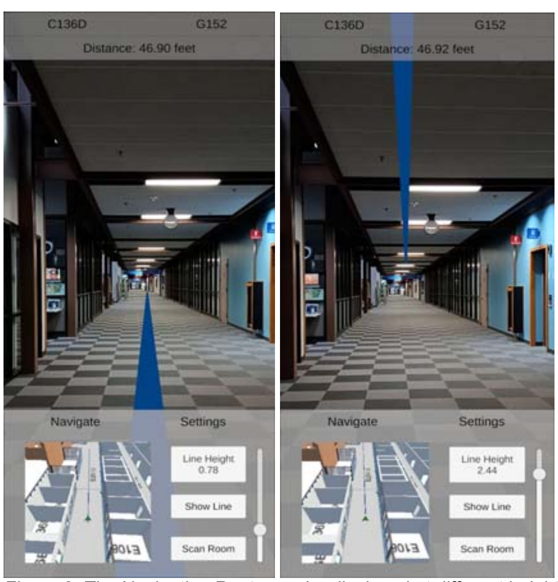

Figure 8. The Navigation Route can be displayed at different heights.

A route is generated for the user to direct them from one location to the next. As the user progresses in their journey, the distance updates accordingly. If the user decides to reselect their end destination during the navigation, both the room and remaining distance will adjust. This feature allows users to gauge the travel time between the two locations.

5. Conclusions

Virtual reality and augmented reality have a wide array of potential use cases. This paper introduced a Mobile Augmented Reality Application for indoor navigation and emergency evacuation. The MARA transforms the traditional way of navigating emergency response into an immersive and interactive experience for the user. The MARA works with Android tablets, mobile phones, and the Meta Quest Pro. It features a 3D model of the campus building constructed using SketchUp. The building floor plan and model created a mini map where key points of interest and exits marked potential user destinations. The navigation system deployed the AI Navigation tool that allowed dynamic and intelligent route generation. The device camera, accelerometer, and gyroscope tracked the user's location in real-time with the help of the AR Foundation. The interface allowed the user to interact with the navigation system and select desired destinations. Additional features included image detection for localization. These components worked together to create a real-time, immersive navigation experience for users.

The potential uses for the MARA are broad. The general navigation functionality can be used outside of emergency scenarios. Visitors of the building can quickly find their way around the campus building to find classrooms, faculty offices, and student service centers. Visitors can use the tool to easily explore the building and various points of interest. The evacuation feature is created for rare scenarios, but by integrating the functionality into general-purpose AR navigation, users can access essential information regarding safety procedures. This feature can be expanded for additional emergency scenarios to help locate fire extinguishers, severe weather shelters, automated external defibrillators, and more. Further work on the application will include development for the Microsoft HoloLens and MagicLeap2.

Acknowledgments

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