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Situational Awareness and Feature Extraction for Indoor Building Navigation using Mixed Reality

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***Abstract*— Indoor navigation in complex building environments poses significant challenges, particularly for individuals who are unfamiliar with their surroundings. Mixed reality (MR) technologies have emerged as a promising solution to enhance situational awareness and facilitate navigation within indoor spaces. However, there is a lack of spatial data for indoor environments, including outdated floor plans and limited real-time operational data. This paper presents the development of a mixed-reality application for indoor building navigation and evacuation. The application uses feature extraction for location sensing and situational awareness to provide accurate and reliable navigation in any indoor environment using Microsoft HoloLens. The application can track the user's position and orientation and give the user-specific information on how to evacuate the building. This information is then used to generate navigation instructions for the user. We demonstrate how this mixed reality HoloLens application can provide spatially contextualized 3D visualizations that promote spatial knowledge acquisition and situational awareness. These 3D visualizations are developed as an emergency evacuation and navigation tool to aid the building occupants in safe and quick evacuation. Experimental results demonstrate the effectiveness of the application, providing 3D visualizations of multilevel spaces and aiding individuals in understanding their position and evacuation path during emergencies. We believe that adopting mixed reality technologies, such as the HoloLens, can greatly enhance individuals' ability to navigate large-scale environments during emergencies by promoting spatial knowledge acquisition and supporting cognitive mapping.**

Keywords*— *Mixed Reality, Situational Awareness, Spatial data, Feature Extraction, Visualization

I. INTRODUCTION

Augmented, or mixed, reality (AR or MR) presents an ideal environment for 3D visualizations in which real-world data can be combined with computer-generated data to provide enhanced architectural floor plans for emergency response operations. It is crucial to be able to move around complex indoor surroundings quickly and effectively, especially in huge structures like hospitals, malls, and airports. Traditional navigation techniques sometimes rely on static maps or signage, which may not be sufficient for meeting the needs of people with visual impairments or cognitive disabilities and may be limited in their ability to provide real-time contextual information.

In recent years, AR and MR technologies have emerged as promising tools for indoor navigation, offering dynamic and context-aware information to users in real-time. Microsoft HoloLens, a popular AR device, presents a unique opportunity to enhance indoor building navigation experiences by providing users with a mixed-reality environment that overlays digital information onto the physical world. By leveraging the spatial mapping and tracking capabilities of HoloLens, users can visualize their surroundings, receive navigational cues, and interact with virtual objects seamlessly and intuitively.

Sharma et al. [1-5] have utilized Microsoft HoloLens for emergency response during a building evacuation. They have tested various use cases for visualizing 3D models and full-scale architectural floor plans. Their HoloLens application allows people to visualize where exits are in the building as well as the shortest path to those exits. They have showcased how augmented reality and mixed reality technologies can be adopted for building evacuation during emergencies. This paper focuses on the development of an indoor navigation system using HoloLens, specifically addressing the challenges of situational awareness and feature extraction. Situational awareness refers to the ability of users to understand their current environment, including their location, nearby landmarks, and potential obstacles. Feature extraction involves identifying and extracting relevant visual cues from the environment to facilitate navigation, such as doorways, staircases, or elevators.

Fig. 1. Display of the floor plan in the Hololens using room numbers as a marker

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Fig. 1 shows the current location in the floor plan using room number as a marker in the HoloLens application. The contributions of this paper lie in the design and implementation of a HoloLens-based indoor navigation system that leverages the device's capabilities to enhance situational awareness by incorporating real-time spatial mapping and localization techniques, enabling users to perceive their surroundings accurately and perform feature extraction in real-time. The application is developed in Unity 3D and incorporates a fast and robust marker detection technique using the Vuforia AR library. Its purpose is to enhance the evacuation experience and facilitate occupants' understanding of evacuation paths during emergencies. The primary objective is to improve evacuation efficiency, reduce injuries, and prevent fatalities in indoor crises such as fires and active shooter events. By utilizing the building's existing features as markers, the HoloLens application triggers the display of the floor plan and the user's current location within the building.

A limited user study was conducted to assess the effectiveness of the application in emergency evacuation scenarios, demonstrating its partial success. The results indicate that most participants believed the HoloLens application could serve as a viable substitute for traditional 2D evacuation plans displayed in buildings. Unlike 2D plans, which can be challenging to visualize, the AR application offers users the flexibility and ability to visualize the building and exits in a 3D space, enhancing their understanding of the evacuation process. The utilization of 3D visualization through AR provides users with a more immersive and intuitive understanding of building layouts and evacuation routes.

The proposed system has the potential to revolutionize the way users navigate complex indoor environments, providing real-time guidance and enhancing the overall user experience. The remainder of the paper is organized as follows: Section 2 provides a review of related work in the field of indoor navigation. Section 3 presents the system architecture, outlining the key components. Section 4 describes the dataset collection process and the feature extraction techniques utilized. Section 5 presents the experimental setup and evaluation results. Finally, Section 6 concludes the paper with a discussion of the findings, limitations of the system, and future research directions.

II. Related Work

Wächter et al [6-7] have also utilized Microsoft HoloLens for interactive evacuation in intelligent buildings assisted by mixed reality. Their evacuation approach uses HoloLens for user guidance for fire protection and the evacuation of new and existing buildings. Their approach also incorporates Bluetooth beacons besides HoloLens to determine the position of the user in the building. The distance to the beacons is determined based on the Received Signal Strength Indicator (RSSI). Their tool uses the position of the beacon with the strongest signal as the position of the user. Based on the user's position their evacuation tool can display the escape routes. On the other hand, Ahn and Han [8] developed RescueMe which is an indoor augmented-reality evacuation system for smartphones. Their mobile system takes snapshots of the nearby room numbers, which are used for image-based positioning.

The gaming engine Unity 3D has been used in developing and simulating building evacuation. Unity was used to simulate train evacuation scenarios [9], hospital evacuation scenarios [10], night club evacuation scenarios [11], and subway evacuation scenarios [12] to understand the group behavior of occupants during an evacuation. Augmented Reality Instructional (ARI) modules for HoloLens have been developed to demonstrate contextualized 3D visualizations to promote and support spatial knowledge acquisition during building evacuation [13]. Virtual Reality Instructional (VRI) modules have been also developed for training purposes [14]. Lately, augmented reality (AR), virtual reality (VR), and mixed reality (MR) have been widely used in the area of building evacuation [15]. VR, AR, and MR have emerged as a critical research tool and a way to enhance evacuation preparedness and effectiveness. AR and MR have also been utilized as training and research tools in pedestrian evacuation research [16] and for construction and industrial safety [17]. AR has also been used to simulate human behavior [18] and for training building occupants [19] in different evacuation strategies.

During evacuation signage plays an important role in directing building occupants to safety. Zhu et al [20] have investigated the impact of surrounding pedestrians on the sign guidance efficiency during building emergency evacuation. Building occupants interact with the evacuation signs and make the evacuation decision after processing the signals [21,22]. Stigall and Sharma [23] have illustrated the use of intelligent signs in mobile augmented reality applications for building evacuation.

III. Situational Awareness and Feature Extraction

Situational awareness is a fundamental aspect of HoloLens applications, particularly in the context of building navigation. By leveraging the capabilities of the HoloLens device, situational awareness can be enhanced, allowing users to understand and interact with their environment effectively. The HoloLens device utilizes spatial mapping technology to create a 3D representation of the physical environment. This allows the application to overlay virtual information onto the user's field of view, providing a mixed-reality experience. By leveraging spatial mapping, users can visualize their current position within the building and gain a better understanding of the layout and spatial relationships of various objects and features. In addition to visual information, HoloLens applications can incorporate other sensory cues, such as auditory or haptic feedback, to enhance situational awareness. For example, the application can provide audio instructions or alerts to guide users toward their destination or notify them of potential hazards. Haptic feedback, such as vibrations or tactile cues, can also be utilized to provide users with physical feedback about their surroundings or to draw their attention to important information. HoloLens applications can provide users with contextual information about their environment. This includes details about nearby points of interest, such as restrooms, elevators, or emergency exits. By overlaying this information in the user's field of view, the application enhances situational awareness and helps users make informed decisions about their navigation choices. This ensures that users have the most up-to-date information to navigate the building effectively.

Fig. 2. Display of the floor plan using feature extraction

HoloLens applications can provide users with clear instructions on evacuation routes, emergency exits, and safety procedures as shown in Fig.2. By overlaying visual cues and providing real-time guidance, the application helps users navigate to safety efficiently and effectively during high-stress situations. Users can share their location and communicate with each other, allowing for coordinated navigation and teamwork. This is particularly useful in scenarios where multiple users need to navigate together or during emergencies that require effective communication among building occupants and navigation from the current location to the shortest or nearest exit displayed on the map will help users in case of emergencies. By combining spatial mapping, tracking, and sensory feedback, HoloLens applications can significantly enhance situational awareness, allowing users to navigate indoor buildings with greater confidence and efficiency. This improved understanding of the environment contributes to a more immersive and intuitive user experience, enabling users to make informed decisions and interact with their surroundings effectively.

Feature extraction is a crucial process in HoloLens applications, as it involves identifying and extracting relevant information from the user's environment to enable accurate interaction and augmentation. In the context of building navigation and other AR experiences, feature extraction plays a significant role in understanding the physical space and enabling the application to overlay virtual content seamlessly. One of the primary features of HoloLens is spatial mapping, which involves creating a 3D representation of the physical environment. Through depth-sensing cameras and sensors, the device captures the geometry and layout of the surroundings. Feature extraction algorithms analyze this spatial data to identify surfaces, objects, and architectural elements within the environment. This information serves as the foundation for accurate augmentation and interaction in the AR application. Feature extraction algorithms in HoloLens applications are designed to detect and track surfaces in real-time. By analyzing the depth and visual data captured by the device's sensors, the application can identify horizontal and vertical surfaces, such as floors, walls, tables, and chairs. This enables the application to accurately anchor virtual content onto these surfaces, creating a seamless blending of the virtual and physical worlds.

Feature extraction techniques in HoloLens applications can also involve object recognition and tracking. By leveraging computer vision algorithms, the application can identify and track specific objects or markers within the environment. This enables the application to overlay virtual content on top of these objects, providing interactive and contextually relevant AR experiences. For example, markers placed on emergency exits can trigger the display of evacuation routes and instructions. The choice of marker depends on the specific requirements of the application, such as the need for precise tracking, interaction capabilities, or the ability to recognize specific objects or patterns in the environment. The commonly used markers are the ones below.

- QR Codes: Quick Response (QR) codes are two-dimensional barcodes that can be easily recognized and decoded by HoloLens applications. QR codes can contain embedded information, such as a unique identifier or a URL, which can be used to trigger specific actions or display relevant augmented reality content. HoloLens applications can detect and track QR codes in the user's environment, allowing for interactive experiences tied to specific markers.
- Visual Markers: Visual markers are specially designed patterns or images that can be recognized by HoloLens applications. These markers typically consist of high-contrast black-and-white patterns arranged in a specific configuration. By analyzing the visual input from the device's cameras, the application can identify and track these markers, enabling the overlay of virtual content on top of the markers. Visual markers can be printed on surfaces or objects, and they provide a reliable means of precise tracking and interaction.
- Object Recognition: Instead of using predefined markers, HoloLens applications can utilize object recognition techniques to identify and track specific objects in the user's environment. Object recognition involves analyzing the visual features of objects, such as their shape, color, or texture, to match them with known models or reference images. This allows the application to overlay virtual content on recognized objects, enabling interaction and augmentation based on the recognized objects' properties.
- Spatial Anchors: Spatial anchors are virtual markers that are placed in the physical space by the user or the application itself. These anchors serve as reference points or waypoints for persistent augmented reality experiences. They enable virtual content to be anchored to specific locations, even if the user moves around or the environment changes. Spatial anchors can be used for various purposes, such as placing virtual objects in specific positions or aligning virtual content with physical elements of the environment.

- Hand Tracking: In HoloLens applications, the user's hands can also serve as markers for interaction. By tracking the user's hand movements and gestures, the application can detect specific hand poses or gestures, such as an open palm or a pinch gesture. Hand tracking enables intuitive and natural interaction with virtual objects and menus in the augmented reality environment.

IV. System Framework of Mixed Reality Application

This paper aims to give a detailed view of the project, and how HoloLens can be used for building evacuation purposes and for navigation in the building.

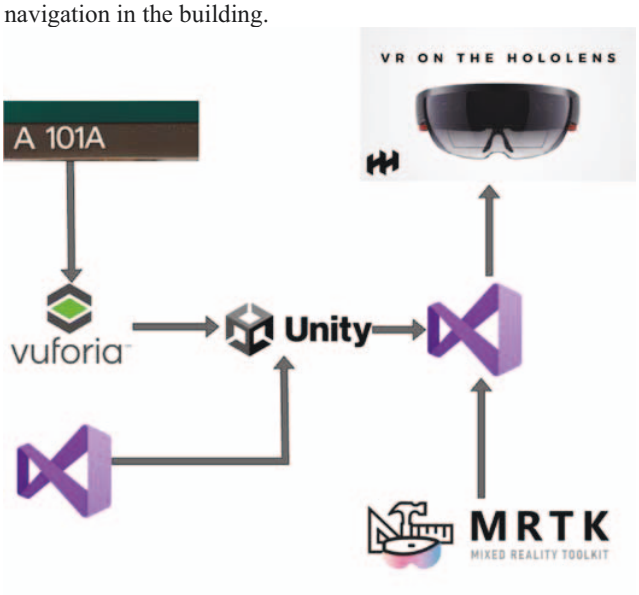

Fig. 3. System framework of Hololens Application

The user initially scans the permanent features such as room numbers in the building and these markers are loaded into the Vuforia database Vuforia assets are loaded into Unity and feature extraction can be performed through Vuforia. Now by using the feature image targeted method, the current location of the user was extracted, and the marker was placed on the map. This is done by assigning a C# code to the respective targeted image using Visual Studio. Thus, the floor map is with the current location and the respective path to the nearest exits in the floor plan. Buttons were created on the GUI and on click of each button the respective wings are highlighted and it would be easy for the user to figure out the departments in the building. The unity application is converted into Visual Studio executable format and deployed in HoloLens using a mixed reality tool kit and the framework is displayed in Figure 3. After deploying the application successfully, a new application icon appears in the HoloLens menu. Tapping the new icon in HoloLens launches the mixed-reality application. When the application is launched it starts scanning the surroundings for targeted images. When the targeted image is in front of the camera, then the application pulls the respected floor plan and current location.

V. User Interaction and Navigation In HoloLens

The developed mixed reality application provides a visualization of the building floor plan. The building consists of two floors and the layout is different on each floor hence the functionality is not similar on both floors. When a user scans a marker in the building, the footprint of the user, where his or her location is pointed at with a pin, and the chosen evacuation route towards an exit are shown in pink. The map also provides different legends which include A Wing, B Wing, D Wing, E Wing, F Wing, G Wing, H Wing, J Wing, K Wing, M Wing, Shelter Areas, AED (Automated External Defibrillator), Stairs to Shelter Areas and Exits. Users can interact with the system through the user interface through the different buttons present on the map. There are buttons for every legend on the map. The program overlays the relevant floorplan over the markers when users scan the marker in with their device. The floor plan shows many legends as well as a pin showing the user's present position.

The matching wing region on the floor plan is highlighted when you click the Wing button in the top right corner of the floor map. Users may now explore and navigate specific areas of interest through this application. Like this, selecting the Shelter Area button focuses on shelter places on the map, alerting users to secure spots in case of an emergency. The floor plan's exits are all highlighted when you click the Exit button. The floor plan's exits are all highlighted when the exit button is clicked. Users may use this to find the closest exit and easily plan their route there. Additionally, when clicked, the buttons for stairs and automated external defibrillators highlight the locations of the stairs and defibrillators in the building, respectively. Having this knowledge handy in an emergency is important.

The floor map's zoom level may be changed by users to view the current location of the user. They may use the zoom-in and out buttons to get a closer look at spaces or details or to get a wider view of the complete floor plan. This floor plan visualization provides a clear picture of the layout and the positions of various rooms, hallways, and facilities, which aids users in finding their way about the facility. The mixed reality application shows the correct floor map when users scan a room number with their HoloLens in an emergency. By selecting the Emergency Navigation button, the program updates the floor plan and shows alternate and suggested routes from the user's present location to the closest exit. The navigation path to the closest exit from the user's present position is dynamically updated on the floor plan each time a user scans a marker.

VI. Evaluation and Results

The developed application is a mixed reality application that enhances the evacuation plan by incorporating additional 3D geospatial data. It was created using Unity and the AR SDK provided by Vuforia, and it is installed on HoloLens using mixed reality and Visual Studio development kits. To initiate the AR experience, a photograph of the evacuation plan was transformed into an AR image target and utilized as a marker. When users point their mobile device camera at the evacuation plan displayed on the wall, AR content is presented on the screen. The conventional 2D evacuation plans posted in the building offer a brief overview of the evacuation strategy and

limited spatial information, serving as a quick reference for occupants who may be unfamiliar with the building or find themselves disoriented during an evacuation. However, without spatial context, it can be challenging for occupants to identify exit locations and determine the most direct path to safety. Through the application's graphical user interface (GUI), users can adjust the scale of the AR content, visualize the shortest path to the exit, display their current location, and enable text and annotations such as room numbers. This mixed reality application empowers users to locate exits and evacuation routes in a three-dimensional space, enhancing their ability to safely evacuate the building and find their way to safety. A limited user study with limited scope was performed to assess the efficacy of the HoloLens application as proposed. The study revealed moderate success and provided evidence of the application's effectiveness in facilitating emergency response during building evacuations. Data was gathered from a sample of 10 participants, consisting of 6 males and 4 females. Following the study, participants were asked to complete a post-study questionnaire, which aimed to gauge their perceptions regarding motivation, usability, educational and training effectiveness, as well as the suitability of the AR application (HoloLens). Figure 4 shows that most of the users felt that HoloLens was more suitable for evacuation. The following are the questions asked in the post-study questionnaire for the user study:

- Used for educational or training purposes in evacuation.
- Substitute for evacuation plans (2D plan) in a building
- Will viewing this HoloLens App help during the real-time evacuation?
- Do you consider this system useful in unknown buildings with complex structures?

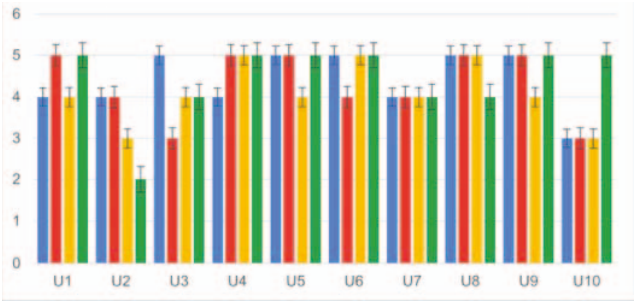

Fig 4. Evaluation of usability of HoloLens Application

According to the findings presented in Fig. 4, the usability of the HoloLens application was met with more positive responses. All participants (90%) expressed the belief that this system would be valuable in unfamiliar buildings with intricate structures, while 80% of participants agreed that using the HoloLens app would be beneficial during real-time evacuations. Furthermore, 90% of participants indicated that the HoloLens application could serve as a viable alternative to traditional evacuation plans (i.e., 2D plans) typically displayed throughout the building. This is particularly significant because relying solely on 2D plans can sometimes make it challenging for users to visualize the building. By utilizing the mixed reality application, such as the one described in this paper, users are equipped with the ability to visually comprehend the building and its exits within a three-dimensional space.

VII. Conclusions

In summary, this paper presents a comprehensive approach to indoor building navigation using HoloLens, focusing on situational awareness and feature extraction. This paper focuses on developing and testing mixed-reality visualizations for emergency evacuation and navigation using HoloLens. The study demonstrates how AR technology can represent complex multi-level spaces. The AR applications provide visual representations of buildings, allowing users to locate exits and find the shortest paths to safety. The system architecture and implementation of the AR application using Microsoft HoloLens for emergency response are discussed. The study shows the potential of AR tools, particularly HoloLens, in enhancing emergency preparedness.

Traditional 2D evacuation plans in buildings show nearby exits but lack spatial context for informed decision-making. By using augmented reality, the plans provide additional context, helping users understand the building layout better (as depicted in Figure 2). The Augmented Reality Application in HoloLens enhances users' spatial knowledge, enabling them to navigate multi-level spaces and evacuate safely during emergencies. AR technology has the potential to transform how we interact with information in the built environment. While 2D maps serve as basic references for locating oneself and finding exits, AR technology allows users to visualize buildings in 3D, providing more comprehensive spatial information.

A user study was conducted to assess the effectiveness of the AR applications on HoloLens, tablets, and mobile phones. The results indicate that the AR applications are useful in unfamiliar buildings with complex structures, with all participants expressing this belief. Additionally, 90% of participants felt that using the HoloLens app would assist them during real-time evacuations.

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