Building Evacuation using Microsoft HoloLens

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Abstract

Evacuation training is critical to the survival of building occupants in the event of an emergency. Live evacuation drills and two-dimensional (2D) floor plans have been the conventional way of informing people of proper evacuation procedures. However, people may not be able to participate in live evacuation drills due to time constraints. Also, 2D floor plans do not provide the perspective and imagery needed to thoroughly know the building layout and, ultimately, the evacuation path that is needed to be taken during an emergency. Augmented reality (AR) has been shown to captivate users, helping them retain information, and do not require users to be present in the environment being simulated. Thus, this work comprises an AR application being built to help users evacuate a building. The application was built for Microsoft HoloLens, a device offering users a 3D, holographic view of building floor plans so that they can have a better perspective of the building, making it easier for them to find a way out of the building during the evacuation. This paper proposes an architecture and describes the design and implementation of an AR application to leverage the Microsoft HoloLens for building evacuation purposes. Pilot studies were conducted with the system showing its partial success and demonstrated the effectiveness of the application in an emergency evacuation.

Keywords: augmented reality, immersive AR, Microsoft HoloLens, building evacuation

1. Introduction

During natural or manmade disasters, people get injured or die because proper evacuation procedures were not given or executed. In 2011, 800 hospital patients situated within an approximately 12.4-mile radius of the Fukushima accident were evacuated via buses or emergency vehicles to safety. The evacuation process of those individuals, however, lasted for a long time, 48 hours in some cases. According to Hasegawa et al [1], no less than 50 elderly patients perished during this evacuation. On September 24, 2005, Hurricane Rita made landfall around the Louisiana-Texas border. The storm prompted 110,000 residents to flee its path. However, the evacuation “indirectly” caused 107 deaths. Carpender et al. [2] cited some issues that were noticed during the evacuation, namely: traffic jams created by there being more people evacuating by road than anticipated, evacuees not having the needed information (or resources) find available shelter, and jammed cell phone networks deeming risk communication by phone futile. In the context of indoor evacuation, over 230 occupying the Kiss nightclub in Santa Maria, Brazil died trying evacuate due to factors such as the massive crowd of evacuees egressing in the same direction and the main exits being blocked by security guards [3]. Those two factors contribute to longer evacuation times, patrons trampling on top of each other while evacuating, and increased the likelihood of fatalities. Had proper evacuation guidance been given before the Fukushima accident, Hurricane Rita, and the Kiss nightclub incident, the deaths in those events would have been prevented.

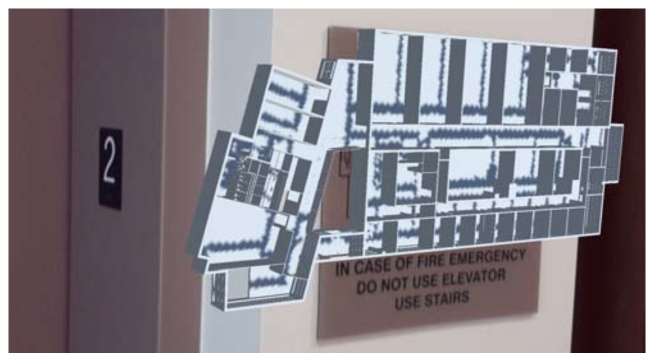

Fig. 1. View of the floor plan from HoloLens using existing 2D plan as a marker

The goal of the project is to enhance the evacuation process by ensuring that all building patrons know all of the building exits and how to get to them, which would improve evacuation time and eradicate the injuries and fatalities occurring during indoor crises such as building fires and active shooters. Fig. 1 shows the 3D representation of the floor plan of the building using HoloLens. It also shows the user his/her location on the floor plan. We have incorporated the existing 2d plans in the buildings as markers to trigger the 3D floor plans. Our proposed AR application was developed using Unity 3D gaming engine and Vuforia SDK. The study has four contributions

1) A novel HoloLens application was developed to give visual representation of a building in 3D space.

2) Implemented the tablet and HoloLens application using Unity 3D by allowing people to see where they are and where exits are in the building.

3) Implemented voice command operations and calculation of safe path to navigate the user to the safest exit through the use of arrows.

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4) Results of usability evaluation for the effectiveness of the HoloLens application in evacuation.

Thus, the HoloLens application enables people to remain connected to the real world, while enriching the environment with more 3D data by enhancing evacuation process. The HoloLens application gives a visual representation of a building floor plan in three-dimension, allowing people to see where exits are in the building as well as their location. AR comprises the user viewing the real world along with computer-generated graphics juxtaposed upon the real world. Whereas virtual reality *completely* replaces the user's physical environment, AR *supplements* it. Alike virtual reality, AR has many uses beyond gaming or entertainment. Okuno et al [4] proposed an AR tool to improve the balance of elderly people to prevent their falling. Liu et al [5] developed an AR system training users on how to perform minimally invasive spine surgery. AR has been proven to be particularly useful in the education and training domain. AR has been shown to enhance concentration and motivation amongst students using it to learn a specific concept and to help students learn by taking what would be a complex subject and make that subject easier to learn to allow students to visualize it in a 3D space and imagining what that subject entails [6]. Popular opinion suggests that using AR in education would be a more effective teaching strategy than traditional teaching methods [7].

Motivated by the visual appeal of AR and the dire need for evacuation training, an AR application was built to train people on the evacuation of the Computer Science Building at Bowie State University. The application was built for Microsoft HoloLens, a pair of mixed reality smart glasses running the Windows 10 operating system that allows users to interface with applications using hand gestures and contains a holographic display. The proposed application was built using Unity3d, the Vuforia AR Toolkit, and the Universal Windows Platform (UWP). This paper seeks to evaluate the application for its effectiveness in evacuation training. The application is described in further detail in Section 3. The evaluation and its results are given in Section 4. Finally, directions for future work are given in Section 5.

2. Related Work

2.1 AR Applications in Education and Training

The Augmented Reality Sandbox, presented in [8], simulates the changes in the Earth's topography using a sandbox with a Kinect 3D camera mounted above it. When users make changes to the topography found in the sandbox using a rake, the camera senses the changes in the distance to the sand and the contour lines and projects those changes to a computer with the AR Sandbox software installed on it. The computer takes the data from the camera, simulates the changes using warm colors for peaks and cool colors for depressions. The computer beams the simulation onto the sandbox using a projector.

A system proposed and evaluated in [9] displays debugging information atop an embedded board, the image of which is captured by a camera connected to a laptop. With this system, students are able to see the connection status between different components on the board, information about where certain components are, the status of programs deployed unto and executed on the board, and the like. An AR system teaching nursing and medical students how to read a pulse was discussed in [10]. The system is comprised of a mannequin's hand containing an AR marker located at the pulse point. The hand is connected to a haptic device that simulates the pulse rate that the user is reading. It is also comprised of a webcam which continuously captures an image of the hand and sends that image to the computer. If the user touches the correct point on the hand, the computer tabulates the pulse rate and sends that information to the haptic device. A user study consisting of 26 participants found that the system provides a realistic experience while being easy to use and effective at teaching pulse measuring.

Birt et al [11] implemented a system giving soon-to-be paramedics airways management skills. Specifically, the system teaches them about how to conduct direct laryngoscopy with foreign body removal. Using the system, students use 3D printed laryngoscope, Macintosh blade, and Magill forceps – tools needed to conduct the laryngoscopy. To interface with the system, users wear a hat with a mobile phone mounted on its bill. The system's display consists of a virtual patient lying in front of the user with its mouth open, allowing the user to conduct the laryngoscopy so that a foreign body can be removed from it. The display also consists of the steps the user needs to take to do the procedure. Srivastava [12] proposed an AR application teaching students Electronics Engineering. When the user holds the device towards a specific image in the student's lab manual, a corresponding video is displayed providing instructions for the experiment. The device also features an Intelligent Breadboard which helps students debug circuits by providing voice-based assistance indicating specifics about the circuit bugs. A user study concluded that students and instructors testing out the application found it to be useful.

Vidal et al [13] have proposed Intramuros – an AR, narrative-based, adventure game where users navigate through Intramuros, Manila, the Philippines using historical markers located at historical sites throughout the city. Along the way, users can "help" troubled historical figures such as Jose Rizal and Pope John Paul II. The game features an in-game 3D map that assists users in navigating towards the markers. Wichrowski [14] have also reported on two AR projects targeting art students.

2.2 AR Applications for Evacuation Training

An AR application in [15] was built to simulate torrential rain and to provoke a significant enough feeling of risk that would lead them to evacuate the premises. Hirokane et al performed an analysis based on the Human Cognitive Reliability (HCR) which categorizes human responses into three different types: skill base, rule base, and knowledge base. Skill base involves seamlessly responding to an event without much thinking; rule base involves responding to an event based on a rule, and knowledge base involves responding to an event by conceptualizing it when it occurs and reacting to it based on the conceptualization. A user study with the system built in [15] found that women respond to disaster using the skill base or rule base response while men respond to disaster using the knowledge base response. This finding confirmed that women had a higher evacuation rate than men when a disaster occurs. Hirokane et al concluded that implementing training that favors the skill base response could enhance the evacuation rate.

Stigall and Sharma [16] built a mobile augmented reality application (MARA) that helps users evacuate a building. When users hold their mobile devices up to a marker, a 3D floorplan corresponding to that maker is generated. The key feature of the Android-based system is the inclusion of "intelligent signs" – visual cues that help users locate each exit in the building and pinpoints a path to those exits. The application also features avatars to indicate the direction to take when evacuating and virtual fire and smoke to invoke the feeling of urgency in the user. Another MARA was built for building evacuation in [17]. Similar to the application developed in [16], a 3D floorplan is generated when the user holds up the mobile device towards the appropriate marker. A user study evaluating the application found that a majority of the participants thought that the application would help them evacuate during a real emergency and that the application is a suitable substitute for a 2D floorplan.

RescueMe was implemented and evaluated in [18]. The AR application helps users evacuate a building by prompting him or her to take a photo of the closest room number. That photo is sent to a server which calculates the exit times of all possible exit paths based on the user's walking speed. The server sends back the path with the lowest exit time. A simulation evaluating RescueMe found that, compared to not using an algorithm for evacuation and using the shortest path algorithm for evacuation, found that the RescueMe algorithm either yielded the lowest evacuation time or the same evacuation time as the shortest path algorithm.

2.3 Microsoft HoloLens

Kučera et al [19] developed an application for the HoloLens with the goal of improving the education of students learning Applied Mechatronics and Automotive Mechatronics. The application features an electronic cart model that can be seen via the HoloLens. Along with the cart, users can see a description of its parts, information about similar vehicles, and a video on e-mobility. Hanna et al [20] discussed pathology residents using the HoloLens application to perform autopsies while drawing within their surrounding environment and communicating with other users in real time. The system discussed in [20] was also used to juxtapose radiographs atop of their respective gross specimens. Those using the system found the HoloLens to be easy wear and use and thought that it provided adequate processing power for their purposes.

3. System Architecture

HoloLens is an augmented reality device which has a capacity to superimpose computer world data onto real-world data. HoloLens contains one main camera and two sensors on each side of the glasses. These two sensors are for scanning the user's surroundings and detecting the user's gestures. The two inputs for this device are voice commands and gestures. The main disadvantage in HoloLens is that HoloLens does not contain GPS. This means we cannot access current location of the user. But, this project requires location service to find the user's current location to guide towards the safest and shortest exit. Image targeting can help to identify the current user location by scanning and capturing surrounding images.

The aim of this project was to develop a tool that will help users evacuate the Computer Science Building on campus safely. This tool will detect the current location of the user, detect the location of the fire, and calculate the safest and the nearest path to the exit. Also, HoloLens implements voice command operations and draws a safe path to navigate the user to the safest exit. The main challenge of this project is to identify the user's location. This challenge was overcome by using existing objects (images) in the physical surroundings. For example, existing 2D floor plans in the building were used for location detection as well as for superimposing 3D floor plan on top of it. Fig. 2 shows the existing signboards of the floor plans in the building.

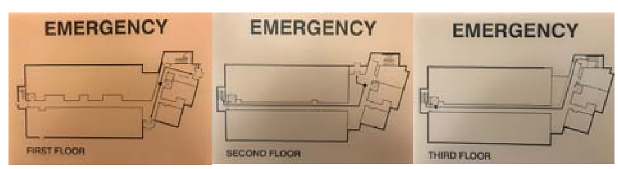

Fig. 2. Existing signboards of different floor plans in the building a) first-floor plan, b) second-floor plan, c) third-floor plan.

On the other hand, creating floor plans in unity can be challenging, but, with the use of Sketchup, creating floor plans becomes much easier. After creating all three floor plans in SketchUp, those floor plans were converted into unity readable format. Vuforia, unity SDK was also incorporated into our project. The Vuforia SDK helped to enable image target services in unity when this SDK file is loaded in unity.

The user can wear the HoloLens with the application loaded by performing bloom gesture in front of HoloLens. The user can select the developed AR application from the list of installed applications. After the application launches, the HoloLens will search for targeted images which are already taken and loaded in HoloLens. Some sample targeted images from the existing surroundings inside the building are shown in Fig. 2. Whenever the user faces the targeted image, HoloLens detects the targeted image. From there, HoloLens will know the user's location since the user's location is pre-loaded. Since HoloLens knows the user's location and contains the floor plan, HoloLens will calculate the distance between the user and the exit and come up with the safest and shortest path. In addition, HoloLens starts directing the user by displaying green arrows in the floorplan. The user can then follow that floor plan to the exit.

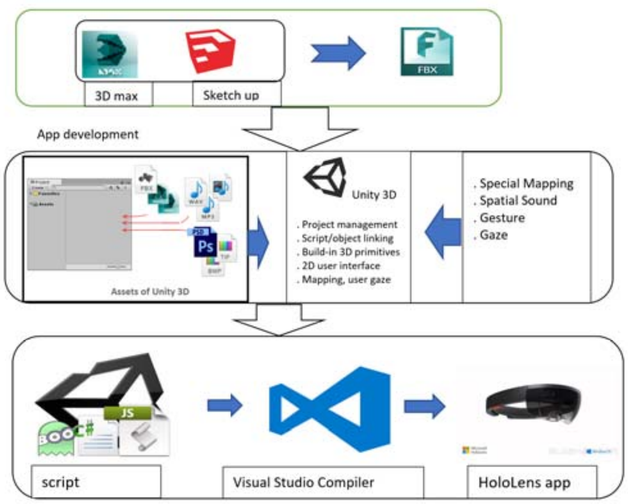

Fig. 3. System Architecture diagram.

Fig. 3 shows the system architecture diagram of our built application. The system architecture was designed in three stages. The three stages were the creation of 3D assets, the development of HoloLens applications, and the deployment of HoloLens applications. The initial step for this process was to create a 3D model of each floor plan for the building. This was done by using Sketch Up tool. After completing the 3D floor plan in sketch up, they were converted into FBX format. FBX format enables 3D data interchange between different platforms. Because unity cannot handle 3D model developed in another format, they were converted into FBX format and then added into unity project assets. In the second stage, app development took place. Here with the help of different features available in Unity like C# scripting, animation, 3D assets, image and texture the project was developed. The third stage was deploying the application into HoloLens. Deploying from unity to HoloLens lead so many challenges like connection issues, packets missing etc. To overcome this problem from unity we generated APK file which can be accessible by visual studio. Next, the APK file was opened in visual studio. Later, we connected the computer and HoloLens with a USB cable. By choosing HoloLens as a targeted device in visual studio we deployed the AR application into HoloLens. Once deploying completed successfully, application appeared in the menu of the HoloLens.

4. Implementation and Deployment

The objective of this paper is to propose an architecture and method to leverage the Microsoft HoloLens for building evacuation purposes. Fig. 4 shows the full life cycle of this project, with different stages involved in developing. Creating project in unity is shown in unity section. Converting built project into visual studio code by selecting required fields in unity settings, this shown under convert. After converting the project into visual studio code, the code will be opened in visual studio. Now HoloLens will pair to the visual studio. After successfully pairing to HoloLens, visual studio will able to deploy the project into HoloLens, this shown under visual studio. After successful completion of deploying, the user can open the application and use it.

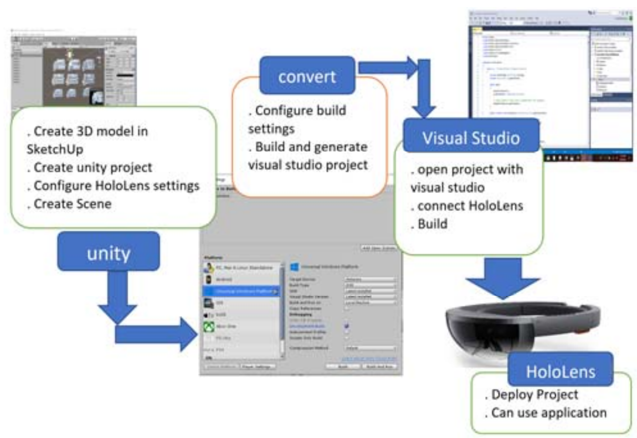

Fig. 4. Build lifecycle of the project.

The implementation and deployment of the project from sketch up to Unity to HoloLens was done in three phases:

Phase 1: During this phase, a 3D floor plans for each of three floors were created using SketchUp software. We then added other objects such as desks, chairs, tables, computers and later textures in the environment. The conversion of the file (from sketch up to fbx format) was carried out so that the floor plans can be added in unity 3D. Later, smoke, fire and other animations were also added.

Phase 2: During this phase, unity 3D app for the project was created. The project to be created was read using visual studio. Then, using visual studio and some specific features, the app was deployed to the targeted device i.e. HoloLens. Vuforia was used for image target method. Initially in Vuforia, we upload all our targeted images. Once the uploading was complete, it gave ranking for the images based on a number of target points extracted. From that report, less ranked images were replaced with better ranked one. The detection of the targeted image depends on this rank. Better the rank better is the HoloLens detects the image. After completing the uploading and the editing from

Vuforia image, the targeted data file was downloaded. This file gave access to use the targeted images in HoloLens.

Phase 3: After successfully deploying the app in the HoloLens, the newly created app was opened and it used the target images as markers for projecting the floor plans and location of the user. Fig. 5 shows how the floor plan is projected after HoloLens detects the targeted image.

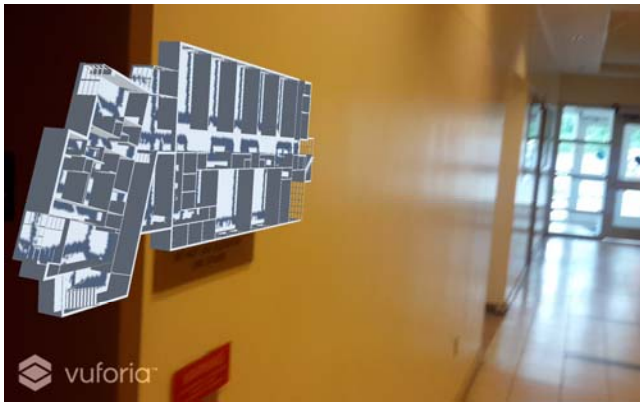

Fig. 5. Projecting floor plan on targeted image for the first floor.

5. Simulation and Results

An AR application for helping people evacuate a building was built using Unity, Visual Studio, and Vuforia.

Fig. 6. Projecting floor plan on targeted image for the second floor.

Fig. 7. Projecting floor plan on targeted image for the third floor.

Figs. 5, 6, and 7 show the projected floor plans in HoloLens using existing 2D floor plans as markers (refer Fig. 1, a, b, and c) in the building. As we had mentioned earlier, existing signboards of the 2D floor plans in the building were used as markers for the HoloLens application.

A very limited user study was conducted to evaluate the effectiveness of our HoloLens AR application. Pilot studies were conducted for the system showing its partial success and demonstrating the effectiveness of the application in an emergency evacuation. We were able to collect 10 responses from participant's. 80% were male participants and 20% were female participants. Post-test part of the questionnaire measured participant's perceptions of motivation, usability, educational and training effectiveness, and AR applications (HoloLens, Mobile phone, and Tablet) appropriateness.

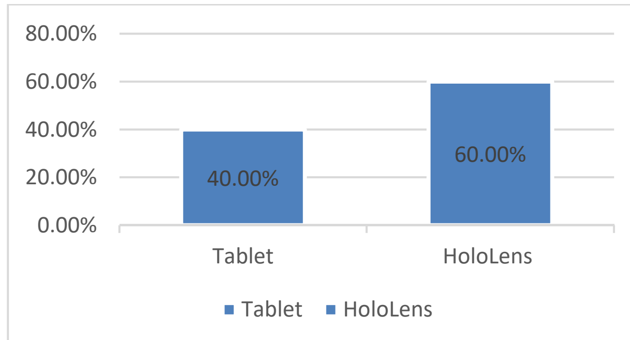

Fig. 8. Device suitability for the study.

Figure 8 shows that the users felt that HoloLens was more suited (60% each) for the study when compared with mobile tablets. On the other hand, 40% users felt that tablet was better as compared to HoloLens. The following questions were asked in the user study

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

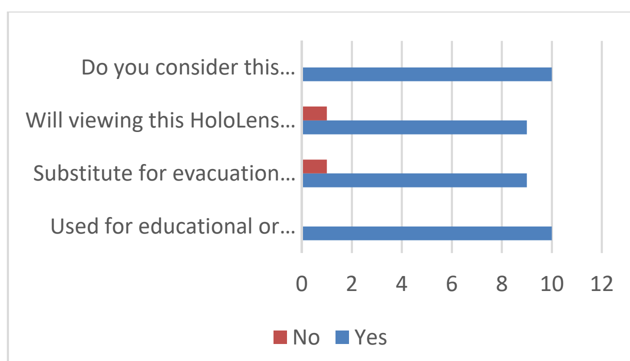

Fig. 9. Evaluation of usability of HoloLens application.

Figure 8 shows that the users felt that HoloLens was more suited (60% each) for the study when compared to the tablet. On the other hand, 40% users felt that tablet was better for the study. The reason for more users preferring tablet was because it was easier to use as compared to HoloLens that uses gestures. HoloLens application received more positive answers in the usability as shown in Figure 9. 100% of the participants felt that this system will be useful in unknown buildings with a complex structure. While 90% participants felt that viewing this HoloLens app will help during real-time evacuation. On the other hand, 90% participants felt that HoloLens application can be used as a substitute for evacuation plans (2D plan) in a building. Usually, the evacuation plans are displayed as a 2D plans in the buildings. Sometimes it becomes difficult for users to visualize a building through a 2D plan. The use of AR application gives the user the flexibility and ability to visualize the building and exits in a 3D space.

6. Conclusion

As our proposed AR application was developed for Microsoft HoloLens, the application offers users an enhanced evacuation experience by offering enthralling visuals, helping them learn the evacuation path they could use during a situation where evacuation is necessary. This paper has presented a novel HoloLens AR application that will help people to safely evacuate a building in case of an emergency situation. It is a fast and robust marker detection technique inspired by the use of Vuforia AR library. Conclusively, it can be recommended that AR technologies like HoloLens should be adopted by people for evacuating others from buildings during emergencies. They should be adopted because they are affordable and offer natural experiences in navigating large-scale environments.

7. Acknowledgments

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