

Identifying Anomalous Behavior in a Building Using HoloLens for Emergency Response

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Abstract

During emergencies communicating in multi-level built environment becomes challenging because architectural complexity can create problems with visual and mental representation of 3D space. Our HoloLens application gives a visual representation of a building on campus in 3D space, allowing people to see where exits are in the building as well as creating alerts for anomalous behavior for emergency response such as active shooter, fire, and smoke. It also gives path to the various exits; shortest path to the exits as well as directions to a safe zone from their current position. The augmented reality (AR) application was developed in Unity 3D for Microsoft HoloLens and also is deployed on tablets and smartphones. It is a fast and robust marker detection technique inspired by the use of Vuforia AR library. Our aim 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 improves evacuation time and eradicates the injuries and fatalities occurring during indoor crises such as building fires and active shooter events. We have incorporated existing permanent features in the building as markers for the AR application to trigger the floor plan and subsequent location of the person in the building. This work also describes the system architecture as well as the design and implementation of this AR application to leverage HoloLens for building evacuation purposes. We believe that AR technologies like HoloLens could be adopted for all building evacuating strategies during emergencies as it offers a more enriched experience in navigating large-scale environments.

1. Introduction

Emergency evacuation and emergency preparedness have become a hot topic in today's day-to-day life due to extreme natural hazards impacting geographic areas as well as social threats like school shootings and terrorist activities that are becoming prevalent. The modern mobile technology offers an opportunity to deploy 3D visualization of building evacuation plans while adding the spatial context that allows users to better understand their position in the building. In this paper, we present an AR application for HoloLens, tablets, and smartphones to overcome the visual limitations associated with traditional static 2D evacuation plans in the building. Our developed AR application offers a 3D visual representation of 3D evacuation plan, path to the various exits; shortest path to the exits as well as directions to a safe zone from their current location. The AR application offers users an enhanced evacuation experience by offering enthralling visuals, helping occupants learn the evacuation path they could use during an emergency situation where evacuation is necessary. A range of use cases was tested to include data visualization, in-situ visualization of 3D models, and full-scale architectural form visualization.

We have introduced AR as an emergent approach for communicating building evacuation information and highlight AR applications to give a mental representation of building in 3D space. We believe that traditional 2D maps in the building are not enough for showing evacuation routes and exits. There is a need to use the current mobile technology to integrate and extend the current 2D maps present in the building to give more-detailed and user-specific instructions to the users. The current 2D evacuation maps in the building inform the building patrons about their position in the floor plan of the building to know exactly where they are. However, knowing the current location in a 2D map for a single-floor building might be easier to navigate toward the exit. But in multi-level spaces knowing the current locations is not enough for the building patrons to visualize and create a mental representation of building floor plan in 3D space due to architectural complexity. This paper presents the research and development of the AR systems that help the users to visualize the 3D floor plan of the building from existing posted 2D floor plan of the building. As shown in Figure 1, when the user looks at the existing 2D plan through the HoloLens, the 3D floor plan gets triggered for display. Thus, the 2D floor plan of the building serves as a marker for the AR application to trigger the 3D floor plan. The projected 3D floor plan also has the capability add more layers of information (text, color, etc.) through the click of buttons through gestures. Figure 1 shows the four buttons (anomaly detection, floor plans, exit, and danger zones), exit locations, current location, room numbers, and arrows to toward the nearest exit on the projected floor plan.

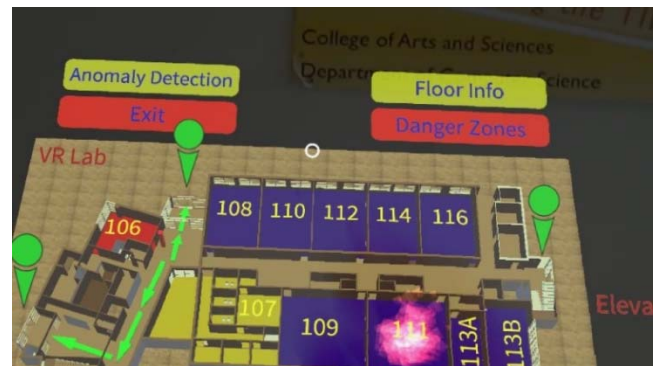


Figure 1. View of 3D floor plan in HoloLens triggered through existing 2D floor plan posted in the building

Emergency evacuation planning is now considered very important for building safety in the event of an evacuation or disaster recovery. Emergency drills help in creating awareness regarding the impending disaster or evacuation and give an insight into the buildings evacuation plan. Conducting evacuation drills is

expensive, time consuming, and disruptive. It is not possible to get real-time data while conducting evacuation drills, as it is impossible to simulate real emergency with emotional stress and panic. It is not possible to incorporate smoke and fire during the evacuation drills due to legal and safety considerations. Geographic information systems (GIS) and advanced 3D visualization technologies provide a way to assess risk during emergency evacuation while simulating emergency conditions. Sharma et al. [1-7] have used computer simulation models [2] and multi-agent [1-3] systems to assess the performance of emergency procedures during evacuation. They have included human emotional behavior by including learning and adaptive behavior through the use of neural network, genetic algorithm, and fuzzy logic [2,4].

The rest of the paper is organized as follows: Section 2 discusses studies related to the one reported in this paper; Section 3 details the system architecture of the application; Section 4 describes the implementation of the application; Section 5 addresses the user study evaluating the application as well as the results of that study; and Section 6 concludes this paper and gives ideas for future work regarding this study.

2. Related Work

Mahfoud et al. [8] have used Microsoft HoloLens to visualize data and information in a real physical environment. They used an immersive visualization approach for investigating abnormal events in real-time using mixed reality. Ogallo [9] argues that the internet application and their provisions brings into light that the Internet of Things (IoT) gains support on the use of HoloLens. These devices are programmed in a way that can link the available virtual data with the internet provisions that can be of help in providing a diversified outlook into the matter of emergency response. Sermet and Demir [10] ratify this idea by mentioning the control of information and information management evident in the use of the HoloLens in provision of decisions. The primary concept, upon which their line of thinking is anchored, is that decisions cannot be made from a vacuum. Microsoft HoloLens created a linkage with a vast flood of information from multiple sources. There is symmetric information that can be driven from the numerous sources of data that can be used to help the user to make out rational decision in response to the emergency [11].

Iguchi et al. [12] have implemented an AR system for training adult users to communicate to children during emergency evacuations. The use of GIS and GPS (Geographical Position Systems) are some of the domains that are constituted in the HoloLens devices. This is because they provide a real-time virtual view on the possible geographical locations and routes that one can use in evading a particularly hazardous situation [13]. Augmented reality application in medicine as safety avenues have used HoloLens in the operations area. During the intensified surgical procedures HoloLens provides a more accurate view of the parts under examination. The ability of these devices to provide a concise view and a 3D vision on the constraining elements of the body ensure there are minimal cases of contrary operations [14]. Vlasblom [15] has used HoloLens in aviation for carrying out risky processes for pilot simulation training. Chen et al. [16] have developed an AR application where markers are placed on pages in a textbook. On the other hand, Kommera et al. [17] have developed an application aimed to increase the users' interest in cybersecurity education by extracting (from articles, feeds, and alerts) data suggesting that a cyber-attack had occurred.

Kučera et al. [18] have discussed reading the use of HoloLens to teach a concept using AR application where the user views a 3D

model of an electric kart along with a description of its parts. Sharma et al., [19-22] have used situational awareness-based AR instructional modules for building evacuation using HoloLens. Vold et al. [23] have used HoloLens for emergency management in a study applying a concept of "flipped gaming", where students discussed learning activities with each other and the instructor acts as a "facilitator".

3. System Architecture

The system architecture of the AR application is shown in Figure 2. It is applicable for Microsoft HoloLens, tablets, and smartphones for building evacuation purposes. The user enables the hardware with the application installed on it. The user points the hardware device camera toward the markers existing permanent features in the building (room number sign boards, etc.). The markers trigger the 3D floorplan generated and superimposed on top of the marker in the hardware device. The graphical user interface (GUI) consists of toggle buttons (anomaly detection, floor info, exit location, and danger zones) that the user uses to toggle the layers on or off. There are two additional features that the user may use to zoom in on the floorplan and to zoom in/out of the floorplan.

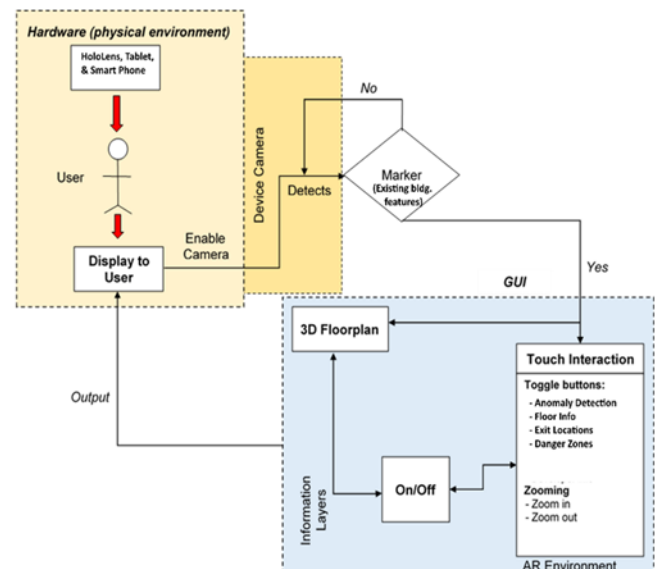


Figure 2. System Architecture of the AR module.

3.1 Mobile Phone Used for AR Application

The mobile phone used for the AR application was the LG G7 ThinQ. The phone features a 16-megapixel rear camera (the camera used by the module), 3120- × 1440-pixel display, 4 gigabytes of RAM, 8-core CPU, accelerometer, and gyroscope. The phone operates the "Pie" release of the Android operating system. Samsung Galaxy Note 9 and S9 were also used for testing the AR module. The phone features the rear camera, which is a dual 12-megapixel system, with a wide-angle lens with switchable apertures and a telephoto lens for zooming in.

3.2 Tablet Used for AR Application

The tablet used for testing the AR application was the Samsung Galaxy Tab S5e. The tablet features a 13-megapixel rear camera, 2560- × 1600-pixel display, 6 gigabytes of RAM, and an 8-core CPU. The tablet runs on the "Pie" version of the Android operating system.

3.3 HoloLens

HoloLens is a pair of mixed reality smart glasses developed and manufactured by Microsoft. It runs on the Windows Mixed Reality platform with the Windows 10 operating system. HoloLens has optics and sensors to deliver 3D holograms pinned to the real world. It has a 64-GB Flash memory and 2-GB RAM memory. It uses gaze tracking, gesture input, and voice support to understand user actions. To maintain internal battery, the device is connected to a 15-W charger. The HoloLens includes an accelerometer, gyroscope, and a magnetometer as well as depth camera with a $120^\circ \times 120^\circ$ angle of view, a 2.4-megapixel photographic video camera, a four-microphone array, and an ambient light sensor.

3.4 Anomalous Behavior

Our proposed AR application gives a visual 3D representation of a building and allows people to see where exits are in the building as well as creates alerts for anomalous behavior for emergency response.

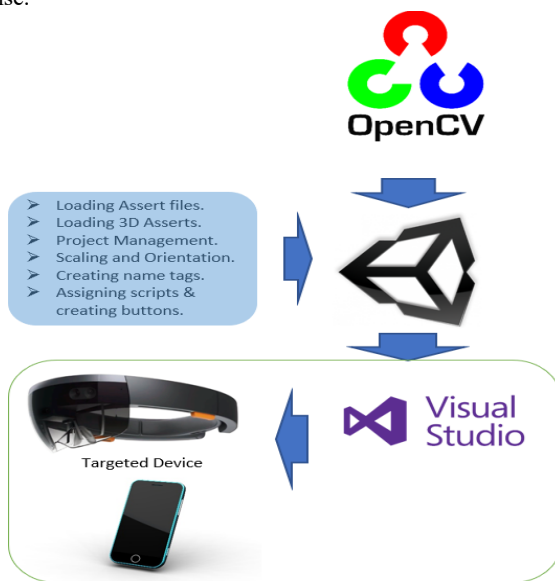


Figure 3. The life cycle of the AR application

Figure 3 describes various steps involved in the application modeling of anomalous behavior. Initially, all different targeted faces to be identified are loaded into Vuforia. From Vuforia the targeted images database is downloaded and added into unity assets. Targeted images and an information panel are created in the environment. After creating an information windows to each targeted image, the visual studio solution is created using Unity. By selecting the HoloLens as the targeted device in the visual studio, the application is deployed. Once it is done, a successful message pops up in the message window as shown in Figure 4. Once it is successfully deployed application into a smartphone and tablet, a new application icon will appear. One can also generate the application for mobile device too by selecting the necessary options in the built panel.

This anomalous behavior feature can work independently without any internet and external database connectivity. During data populating mode, the application generates its own database. In this mode when the application is opened in the device, the camera opens automatically and starts detecting faces. The GUI of the tablet and smartphone has the option to change the camera from front view to back view and vice versa (refer to Figure 4). When user clicks “add person” button, a face appears on the right-hand side of the window.

This way the user can load multiple faces into the application database. The user can empty the database by clicking “delete all” button. Once the user clicks the “delete all” button, all faces that are loaded in the database are removed. By this way the user can create their own database. In Figure 4, one can see the faces loaded in the database. By clicking “load” button on the GUI, the application loads all the faces and the application switches to scanning mode. In this mode the application will scan all the faces in front of the device camera. It has an ability to scan multiple faces simultaneously. If the matched face is found, the database will be highlighted with a blue box, and the original photo of that face will be shown on top of the screen in a small box. If there is no match found, the box will be empty as shown in Figure 4 (a). The anomalous behavior feature is currently only deployed in tablets and smartphones.

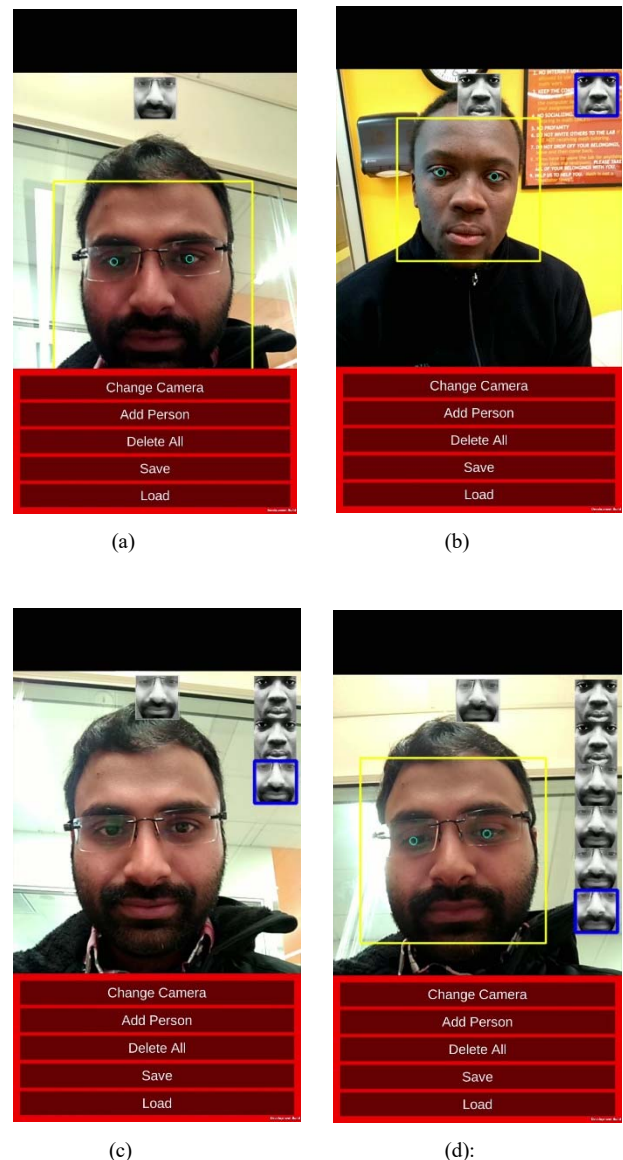


Figure 4. Populating the application database with different faces: (a) application recognizing the participant faces, (b) loading first face into database by clicking add person button, (c) loading second person face into database, and (d) all participants faces.

4. Development and Implementation of AR Application

The implementation of the AR application was done in three phases.

4.1 Phase 1: Modeling

Phase 1 of the AR application consisted of modeling the environment. The implementation began with the modeling the 3D floorplans and other models using SketchUp and 3dsMax. The three floorplans were modeled for the Computer Science Building on campus. Objects such as tables, desks, boards, chairs, and computers were added to provide realism. Textures were added to the floorplans and objects. Once the three floor plans were modeled, they were exported into Unity 3D gaming engine.

4.2 Phase 2: Exporting to Unity 3D and Vuforia Integration

In Phase 2, the environment was exported from Google Sketch-up and imported into Unity 3D. The AR application uses permanent features in the buildings as markers. As shown in Figure 5, existing signboards mounted in front of entranceways throughout the building containing room numbers and names were used as markers to augment the 3D floors in the building.

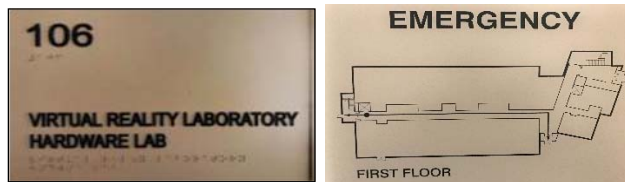


Figure 5. Markers for AR application

4.3 Phase 3: Creating the GUI

In this phase, buttons were added above the floorplan for best viewing in HoloLens. A color layer was also added along with the floor numbers to differentiate the rooms more easily. The scripts for pinch hand gesture movement was created for zooming in and out for the 3D floorplan. A similar option was enabled for tablets and mobile devices. In HoloLens, the size of the 3D floor plans is automatically adjusted according to the eye covering the area.



Figure 6. View of the AR application in HoloLens with gesture control icon

Figure 6 shows the developed AR application with circle icon for hand gesture taping. After the floor plan is triggered in the hardware device, the user has an option to enable different layers to add more contextualized information to the floor plans. The red marker in Figure 6 shows the current location of the user, and green arrows guide the user to the nearest exit from the current location. The user can click or tap the buttons to add more information as layers on the floor plan (refer Figure 1 and Figure 6). As a result, the user can use this AR application for not only emergency evacuation, but also for indoor navigation.

This Version of the AR application was deployed onto Android devices (phones and tablets) and the HoloLens. Before deploying onto the devices, Android was indicated as the target platform and the SDK version was selected in Unity's build settings. For deployment onto the HoloLens, Windows was selected to be the target platform. After developing the AR application in Unity 3D, visual studio was used to generate the AR application. From Visual Studio, the target device was selected and deployed for HoloLens.

5. Discussion

This paper demonstrates how AR may be used to facilitate situational awareness and knowledge acquisition in complex multilevel floor plans in a building. We have presented AR as tool for training and education by communicating spatial information to the patron of the building in response to emergency evacuation and preparedness for public safety. We have used emergency evacuation as a framework to illustrate how AR technology can be applied to communicating in multi-level built environments. The visualizations developed using Unity offer a more GIS-like experience that allows the user to activate different layers for showing various exits, shortest paths to the exits, as well as directions to a safe zone from their current position.



Figure 7. Spatially contextualized emergency exit locations via tablet

Figure 7 shows the spatially contextualized emergency exit locations via tablet. The figure shows the user carrying a tablet and viewing the 3D floor plans triggered through the room number sign post (permanent features) in the building. It also shows the current location, and green arrows show the path toward the exit. On the other hand, Figure 8 shows the 3D spatially contextualized emergency exit locations via mobile phone.

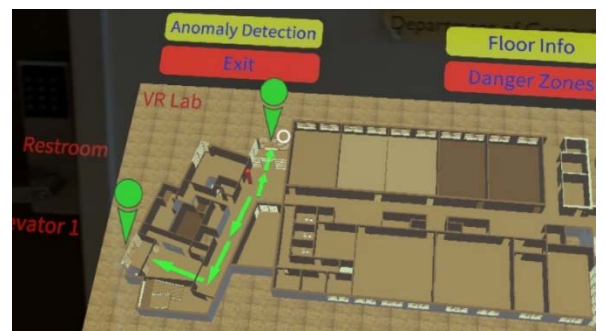


Figure 8. Spatially contextualized emergency exit locations via mobile phone

6. Conclusions

This paper presents the research and development of prototype AR HoloLens application that gives a visual representation of a building on campus in 3D space, allows people to see where exits

are in the building, and creates alerts for anomalous behavior for emergency response such as active shooter. This work presents the novel approach of representing multi-level spaces in 3D form using AR technology. The AR application was developed in Unity 3D for Microsoft HoloLens, tablets, and smartphones using a robust marker detection technique inspired by the use of Vuforia AR library. This work describes the system architecture and implementation of this AR application deployed on Microsoft HoloLens, tablets, and smartphones for building evacuation purposes. We have incorporated the current 2D evacuation maps in the buildings as markers to trigger a 3D floor plan. We have also used the existing permanent features such as room numbers in the building as markers to trigger the floor plan and subsequent location of the person in the building. We have enhanced spatial perception and situational awareness of multilevel spaces through situated AR evacuation displays to support emergency preparedness. We hope our research in proposed AR application will lead to future applications for situated AR evacuation and demonstrate how AR tools may be used to improve the emergency evacuation and preparedness communication.

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References

- [1] S. Sharma, "Avatarsim: A multi-agent system for emergency evacuation simulation", *Journal of Computational Methods in Science and Engineering*, Volume 9, No. 1,2, page S13-S22, ISSN 1472-7978, (2009).
- [2] S. Sharma, S., Ogunlana, K., P., Scribner, P., Grynovicki, "Modeling human behavior during emergency evacuation using intelligent agents: A multi-agent simulation approach", *Springer special issue of Information Systems Frontiers on Disaster Management and Information Systems*, DOI: 10.1007/s10796-017-9791-x, ISSN 1387-3326, page 1-17, (2017).
- [3] S. Sharma, H. Singh, A. Prakash, "Multi-agent modeling and simulation of human behavior in aircraft evacuations", *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 44, No.4, (2008).
- [4] Sharma, S., and Ogunlana, K., "Using Genetic Algorithm & Neural Network for modeling learning behavior in a Multi-Agent System during Emergency Evacuation", *International Journal of Computers and their Applications*, IJCA, Vol. 22, No. 4, page 172-182, Dec. 2015.
- [5] Sharma, S., "Use of Favorite Goal in Agent Based Modeling and Simulation", *International Journal of Computers and their Applications*, IJCA, Vol. 19, No. 1, page 1-9, Mar. 2012.
- [6] Sharma, S., "Fuzzy approach for predicting probability of reaching a target in a battlefield environment", *International Journal of Computers and their Applications*, IJCA, Vol. 17, No. 1, Mar. 2010.
- [7] Sharma, S., "Military route planning in battle field simulations for a multi-agent system", *Journal of Computational Methods in Science and Engineering*, Volume 10, No.1,2, page S97-S105, ISSN: 1472-7978, 2010.
- [8] Mahfoud, E., Wegba, K., Li, Y., Han, H., & Lu, A. "Immersive Visualization for Abnormal Detection in Heterogeneous Data for On-site Decision Making", *Proceedings of the 51st Hawaii International Conference on System Sciences*, (2018).
- [9] Ogallo, G. G., "IoT-Enhancing Data-driven Decision-making in Higher Education. Case Study of Ohio University (Doctoral dissertation, Ohio University), (2018).
- [10] Sermet, Y., & Demir, I. "Towards an information centric flood ontology for information management and communication", *Earth Science Informatics*, page 1-11, (2019).
- [11] West, D. M., "What happens if robots take the jobs? The impact of emerging technologies on employment and public policy". *Centre for Technology Innovation at Brookings*, Washington DC, (2015).
- [12] K. Iguchi, H. Mitsuhara, M. Shishibori, "Evacuation Instruction Training System Using Augmented Reality and a Smartphone-based Head Mounted Display", *2016 3rd Int. Conf. on Information and Communication Technologies for Disaster Management*, © IEEE. doi: 10.1109/ICT-DM.2016.7857220, (2016).
- [13] [6] Hu, P., Dhelim, S., Ning, H., & Qiu, T. (2017). Survey on fog computing: architecture, key technologies, applications and open issues. *Journal of Network and Computer Applications*, 98, page 27-42.
- [14] Brown, L. "New Technologies: A Transfer of Power", *Design Management Review*, 28(1), page 18-21, (2017).
- [15] Vlasblom, J. I. D. "Creation of a HoloLens Application to Support Instructors during Pilot Simulation Training", *Master's thesis*, (2018).
- [16] H. Chen, K. Feng, C. Mo, S. Cheng, Z. Guo, and Y. Huang, "Application of Augmented Reality in Engineering Graphics Education", *IEEE Int. Symp. IT in Medicine and Education*, © IEEE. doi: 10.1109/ITIME.2011.6132125, (2011).
- [17] N. Kommera, F. Kaleem, S.M.S. Harooni, "Smart Augmented Reality Glasses in Cybersecurity and Forensic Education", *2016 IEEE Conf. Intelligence and Security Informatics (ISI)*, Tucson, AZ, page 279-281, Sept. 28-30, (2016).
- [18] E. Kučera, O. Haffner, and R. Leskovský, "Interactive and Virtual/Mixed Reality Applications for Mechatronics Education Developed in Unity Engine", *Cybernetics & Informatics, Lazy Pod Makytou, Slovakia*, page 25-30, Jan. 31-Feb. 3, (2018).
- [19] Sharma, S., Bodempudi, S.T., Scribner, D., Grynovicki, J., Grazaitis, P., "Emergency response using HoloLens for building evacuation", *Proceedings of 21st International Conference on Human-Computer Interaction*, DOI: https://doi.org/10.1007/978-3-030-21607-8_23, Online ISBN 978-3-030-21607-8, Orlando, FL, July 26-31, HCII 2019, *Lecture Notes in Computer Science*, Vol. 11574, page 299–311, (2019).
- [20] Stigall, J., Bodempudi, S.T., Sharma, S., Scribner, D., Grynovicki, J., Grazaitis, P., "Use of Microsoft HoloLens in indoor evacuation", *International Journal of Computers and their Applications*, IJCA, Vol. 26, No. 1, (2019).
- [21] Stigall, J., Sharma, S., "Evaluation of Mobile Augmented Reality Application for Building Evacuation", *Proceedings of 28th International Conference on Software Engineering and Data Engineering (SEDE 2019) in San Diego, CA, Sep 30-Oct 2*, (2019).
- [22] Stigall, J., Bodempudi, S.T., Sharma, S., Scribner, D., Grynovicki, J., Grazaitis, P., "Building Evacuation using Microsoft HoloLens", *Proceedings of 27th International Conference on Software Engineering and Data Engineering (SEDE 2018)*, New Orleans, LA, USA, page 20-25, Oct. 8-10, (2018).
- [23] T. Vold, H. Haave, O. J. S. Ranglund, G.O. Venemyr, B.T. Bakken, L. Kjøning, & R. Braun, "Flipped Gaming – testing three simulation

games”, 2018 17th International Conference on Information Technology Based Higher Education and Training (ITHET), Apr. 26-28, (2018).

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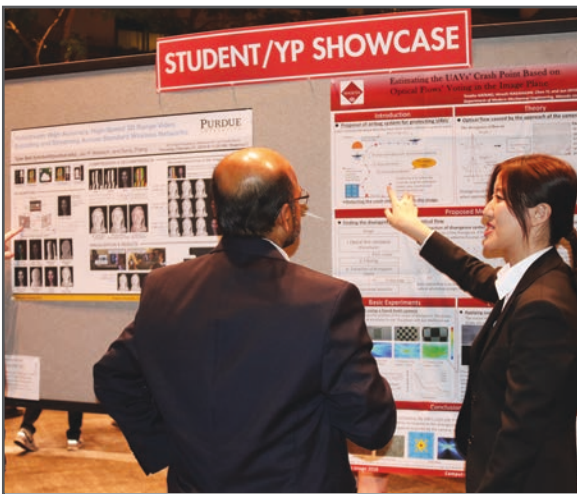
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