Mixed Reality for Post-Disaster Situational Awareness

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ABSTRACT
When disaster strikes, what once was, no longer is; and what is, is unrecognizable. The ability to understand the way things were is critical for those working in the response, rescue, and recovery phases of disaster management, from first responders to insurance claims agents. A team at the Johns Hopkins University Applied Physics Laboratory (APL) is developing a system that uses 3-D modeling data and precise positioning data from GPS to display an image of structures “in place” using a mixed reality head-mounted display for first responders in a disaster scenario. The proof of concept revealed significant challenges that need to be solved, and we have already proposed solutions and are working to test them. This technology is designed to assist first responders but will also have applications in other areas that require real-time data presentation, such as battlefield situational awareness.

INTRODUCTION
After a disaster, the lay of the land can be unrecognizable. Buildings that once stood might be gone, with nothing more than debris remaining in their place. Tornadoes, floods, explosions, and other mass casualty events leave first responders little time to get to victims and even less time to get them help. However, by taking advantage of technology developments and available data, we have the potential to improve the situational awareness of disaster management personnel so that they can respond as quickly and appropriately as possible. Much of the required data already exist although not in a unified manner. For example, Google has mapped the entire nation, providing street-level views of points across the United States, yet this information is not combined with the data local jurisdictions typically require, such as architectural and engineering drawings as part of their permitting processes.

We can use these collected data to create virtual 3-D maps of the world as it was before the disaster struck. We can then take advantage of technology to display this information in a mixed reality (MR) system, like the Microsoft HoloLens, creating a head-mounted display (HMD) of the way things used to be before the disaster. This view can assist first responders and rescuers, showing them where parts of buildings once stood, what form structures took, and other metadata collectible from public data sources. This metadata might include altitude, locations of power lines and underground pipelines, or information as elementary as telephone data from the phone book. Having this information may also
help rescuers determine where victims might be so that they can expedite rescue while helping victims avoid hazards such as gas and electrical mains.

This preliminary report explains the proof-of-concept system an APL team developed and tested by using a building under construction on APL’s campus. It also outlines two major problems encountered in the development of this system. Finally, it proposes future directions for making the proof of concept more resilient and for developing a field-deployable system.

**PROOF OF CONCEPT**

The proof of concept took advantage of the construction of a new building on the APL campus. Teams working on the new building, B201, had already developed a 3-D representational model of the building from the architectural drawings. This model was imported into the Autodesk Revit computer-aided design (CAD) software to create virtual reality (VR) walkthroughs and dynamic displays of how the internal aspects of the building may be configured. Figure 1 shows the model in a VR environment. (See the article by Boyle, Dean, and Kraus, in this issue, for details on the B201 project.)

For this work, only the outside shell showing the basic design and structure of the building was used. The existing 3-D model was imported into Unity, which was used to create an application for the HoloLens allowing a holographic version of the building model to be aligned with the real-world building. The HoloLens application made use of preset calibration locations to accurately align the holographic building model with the actual building. These preset calibration locations require the user to stand at a certain physical location and run an alignment algorithm that correctly positions the hologram in the user’s surroundings. Some manual fine-tuning is required to get a high degree of accuracy in the alignment, but a completely automated approach is also feasible.

With position determined, the HoloLens can determine its own orientation in three-space and render virtual objects over the view of the wearer. Our goal was to allow the wearer to walk around the B201 construction site and see the shell of the building in its expected place, as shown in Figure 2.

**Figure 1.** Snapshot from an external view of the B201 VR model. The model was created to support VR walkthroughs and dynamic displays of internal aspects of the building and was used this model in the proof of concept described in this article.

**Figure 2.** Stephen Bailey demonstrating the use of the HoloLens and controller on the construction site. The existing 3-D model was imported into Unity to create an application for the HoloLens that enabled the wearer to walk around the B201 construction site and see the shell of the building in its expected place.
Mixed Reality for Post-Disaster Situational Awareness

STATUS

The holographic model of B201 was successfully aligned with the construction site, as shown in Figure 3; however, there are still significant challenges to address. The first challenge is that the alignment of the holographic building model with the actual construction site tends to drift over time. The second challenge is the need to provide data to the HMD in an automated fashion at the site of a disaster.

Challenge 1—Improving Location

As the HoloLens moves through its environment, it can accumulate error in its positional tracking, causing the holographic building model to lose its alignment with the actual construction site. Periodic recalibration is necessary to maintain the buildings’ alignment. Our preset calibration locations are not well suited to this type of continuous recalibration, but it is easy to add a GPS sensor to the HMD for a better source of continuous positioning information.

Civilian GPS guarantees a global accuracy of less than or equal to 7.8 m with a 95% confidence interval. In practice, the GPS accuracy of cellular phones trends closer to 5 m. For directions to a child’s birthday party, 5-m accuracy is more than sufficient. However, when attempting to place a location precisely, as in our use case, the image of a building could be off by as much as a car length. Furthermore, GPS provides substantially less accurate information about altitude than about latitude and longitude.
Our current calibration step also requires some manual fine-tuning to the orientation and altitude of the building model as viewed through the HMD. This can also be achieved with a sensor-based approach, which is far more desirable long term. Ideally the entire calibration process would be invisible to the user, with recalibration occurring at continuous intervals mitigating the effect of the HoloLens’s imperfect tracking outdoors.

Challenge 2—Creating 3-D Models of Existing Structures

The second major challenge is creating a database of objects and adapting it to the MR display system. Google Earth provides 3-D renderings of buildings across the United States.\(^9\) In addition to these data, Google has also captured and provides street-level imagery of structures.\(^10\) Both of these data sets provide imagery and models that can be used to support the MR scenario developed.

Additional data are collected by local planning and zoning departments. The process of approving site plans and permitting buildings typically involves the submission of engineering and architectural drawings of a proposed structure. These data, however, are difficult to adapt to our system. Much of the information is currently available only via hard copies on paper. Further, these data are not necessarily consistent with actual conditions on the ground. Structures may have been changed with approval but without updated drawings, or structures could have changed without any formal approval at all.

Regardless of the source of data, the data sets are large and will be difficult to process on devices like the HoloLens. One way to combat this would be to deliver the data to the device using a wireless network. However, cellular networks are frequently unavailable in the immediate aftermath of a disaster.\(^11\) In some cases, cellular towers lose communication with the full network, lose power, or simply become overloaded. The HMD user could be outfitted with an additional embedded compute device to offload some data processing and provide additional data storage. It would also be possible to set up a wireless network at a disaster site to provide this supporting infrastructure without the need for rescue workers to carry additional hardware.

**FUTURE DIRECTIONS**

APL is actively working to solve the two challenges described above while at the same time thinking about future applications of the system. Initially, we propose expanding on our work to achieve the same result in a GPS-denied environment. While natural disasters are not coincidental with attacks on the GPS, potential adversaries may seek to use GPS denial to worsen the effects of a natural disaster, or adversaries may couple a GPS denial of service with other attacks to complicate rescue and recovery efforts.\(^12\)

Our approach will use dynamic landmark identification to find objects surviving the incident and then use those items to locate the wearer and objects within the 3-D model of the environment. In addition to responding in a GPS-denied scenario, this approach will benefit other situations by reducing the resources necessary to maintain a location fix, as visual landmark identification and accelerometers are together more energy efficient than GPS receivers.

Secondarily, we propose developing a content delivery network that can be set up on demand at a disaster site. This will remove the need for rescue workers to connect their HMDs to any preexisting network that might not be available in a disaster scenario. This can also reduce the burden on any remaining cellular network so more resources are available for other emergency personnel.

**CONCLUSIONS**

This article described a proof of concept that demonstrates the ability to place 3-D images of buildings into their physical location in the real world by using MR. Such a system can be used to support first responders in rescuing disaster victims and preventing additional injuries during response operations. As the baseline for an expanded system, we expect this system to become an HMD for first responders and disaster recovery professionals.

During development efforts, two significant challenges were encountered. The first of these challenges was keeping holographic information accurately aligned with the real world when viewed through an MR HMD. The second was developing a 3-D model sufficient for our purposes that was compatible with the HoloLens. We propose continued development to further improve location precision and real-world integration. When fully developed, this system will have applications in disaster response and other areas that require real-time data presentation, such as battlefield situational awareness.

**REFERENCES**

Mixed Reality for Post-Disaster Situational Awareness

Please note that the original text contains several errors and inconsistencies in formatting and content. The following is a corrected and structured version of the text:

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James P. Howard is the lead data scientist and service manager in APL’s Information Technology Services Department. He holds a bachelor’s degree in mathematics from the University of Maryland, College Park, a master of science in environmental engineering and science from Johns Hopkins University, a master of public administration from the University of Baltimore, and a doctorate in public policy from the University of Maryland, Baltimore County. Since joining APL in 2016, he has led projects to make the internet more resilient to disaster and to model the outcomes of epidemics for novel infections. Other projects have involved satellite communications, prediction of disruptive events, blockchain analysis, and other topics. He has taught mathematics and statistics and public management. Dr. Howard has written two books on flood insurance and computational mathematics and has edited two more collected volumes on operations research and teaching mathematics via distance education. He is a Fellow of the British Computer Society. His email address is james.howard@jhuapl.edu.

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Arthur O. Tucker is a member of APL’s Senior Professional Staff and a software systems engineer. He holds a BS in electrical engineering and computer science from Duke University and an MS in computer science from Johns Hopkins University. He has expertise in AR, space ground systems, and computer and network security and has been developing software for diverse applications for nearly 20 years. Arthur has managed multiple projects, has supervised staff, and has made technical contributions to complex systems across a variety of domains. In addition to being the ARMOUR X co-investigator, he is the principal or co-investigator on a variety of AR efforts at APL involving space mission design, scientific visualization, and digital twins. Arthur routinely presents on technical topics to diverse audiences including sponsors, clients, and other stakeholders; project teams; and symposia, workshop, and conference attendees. His email address is arthur.tucker@jhuapl.edu.

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Stephen A. Bailey is a software engineer in APL’s Air and Missile Defense Sector. He has a BS in premedical studies from Penn State and an MS in computer science from Johns Hopkins University. He has a diverse set of skills including full-stack web applications development, virtual/mixed reality devices and development, and Unity game engine development. He has worked as the principal investigator for multiple independent research and development (IRAD) projects at APL and serves on an APL committee that funds innovative new ideas across the Air and Missile Defense Sector. His email address is stephen.bailey@jhuapl.edu.

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James L. Dean is a computational engineer in the Information Technology Services Department at APL. He holds a BS in applied physics and mathematics from the University of Northern Iowa and an MS in aerospace engineering from Old Dominion University. He has a broad range of expertise including numerical modeling and simulation, data science and visualization, and software development for applications involving mixed reality, graphics rendering, and the Unity game engine. James has contributed to numerous mixed reality projects throughout APL with applications in missile defense, fluid dynamics analysis, construction, and systems engineering. His email address is james.dean@jhuapl.edu.

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Michael P. Boyle is supervisor of the Mechanical Engineering Systems Analysis and Design Group in APL’s Research and Exploratory Development Department. He has a BS and an MS in mechanical engineering from the University of Maryland, College Park. Michael’s background...
is in computer-aided design (CAD) and finite element analysis (FEA). As group supervisor, he facilitates the group’s work while improving standards, processes, and procedures. He also supports the design and analysis of mechanical and electromechanical systems. Michael has written edge detection software to help create detailed finite element models of pediatric skulls and proximal femurs and developed a process for resolving a complex, obstructed 3-D field of view into a 2-D blockage map. Other experience includes analysis of a composite shipboard antenna, the platform of a communications tower, two airplane-mounted gimbals, and an underwater pressure vessel. He is an instructor for the Johns Hopkins University Engineering for Professionals Program. His email address is michael.boyle@jhuapl.edu.

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Christopher D. Stiles is a computational physicist and supervisor of the Multiscale Mathematical Modeling Section in APL’s Research and Exploratory Development Department. He holds a BS in mathematics and physics and a PhD in nanoscale science and engineering, both from the State University of New York at Albany. Christopher specializes in computational approaches of materials science to model real-world systems—developing, using, and advising on the use of cutting-edge computational methods. His email address is christopher.stiles@jhuapl.edu.

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