# 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,[1] 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.[2]

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,[3] 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

**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.

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,[4] 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.[5] 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 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.


**Figure 3.** Successful model of B201 in the context of its location. The top image shows the construction site, and the bottom image shows the 3-D model positioned to the construction site.

## 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.[6] In practice, the GPS accuracy of cellular phones trends closer to 5 m.[7] 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.[8]

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


[1]L. Vincent, "Taking online maps down to street level," *Computer*, vol. 40, no. 12, pp. 118–120, 2007, https://doi.org/10.1109/MC.2007.442.

[2]C. S. Han, J. Kunz, and K. H. Law, "Making automated building code checking a reality," *Facility Manage. J.*, pp. 22–28, 1997.

[3]G. Evans, J. Miller, M. Iglesias Pena, A. MacAllister, and E. Winer, "Evaluating the Microsoft HoloLens through an augmented reality assembly application," in *Proc. Degraded Environments: Sensing, Processing, and Display 2017*, vol. 10197, p. 101970V.

[4]S. L. Kim, H. J. Suk, J. H. Kang, J. M. Jung, T. H. Laine, and J. Westlin, "Using Unity 3D to facilitate mobile augmented reality game development," in *Proc. 2014 IEEE World Forum on Internet of Things (WF-IoT)*, 2014, pp. 21–26.

[5]K. Fan, J.-M. Seigneur, J. Guislain, S. Nanayakkara, and M. Inami, "Augmented winter ski with AR HMD," in *Proc. 7th Augmented Human Int. Conf.*, 2016, p. 34.

[6]J. Ventura and T. Höllerer, "Wide-area scene mapping for mobile visual tracking," in *Proc. IEEE Int. Symp. on Mixed and Augmented Reality (ISMAR)*, 2012, pp. 3–12, https://doi.org/10.1109/ISMAR.2012.6402531.
[7]L. Dawson, "Life without satellites," in *War in Space*, Cham, Switzerland: Springer, 2018, pp. 1–11.
[8]P. A. Zandbergen and S. J. Barbeau, "Positional accuracy of assisted GPS data from high-sensitivity GPS-enabled mobile phones," *J. Navigation*, vol. 64, no. 3, pp. 381–399, 2011, https://doi.org/10.1017/S0373463311000051.
[9]S. R. J. Sheppard and P. Cizek, "The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation," *J. Environ. Manage.*, vol. 90, no. 6, pp. 2102–2117, 2009, https://doi.org/10.1016/j.jenvman.2007.09.012.
[10]D. Anguelov, C. Dulong, D. Filip, C. Frueh, S. Lafon, R. Lyon, A. Ogale, L. Vincent, and J. Weaver, "Google street view: Capturing the world at street level," *Computer*, vol. 43, no. 6, pp. 32–38, 2010, https://doi.org/10.1109/MC.2010.170.
[11]J.-S. Huang and Y.-N. Lien, "Challenges of emergency communication network for disaster response," in *Proc. 2012 IEEE Int. Conf. on Communication Systems (ICCS)*, 2012, pp. 528–532, https://doi.org/10.1109/ICCS.2012.6406204.
[12]C. Curriden, "Why Beidou could help protect GPS," *Georgetown J. Int. Affairs*, vol. 19, pp. 90–96, 2018, https://doi.org/10.1353/gia.2018.0011.

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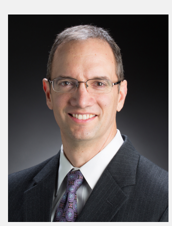

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