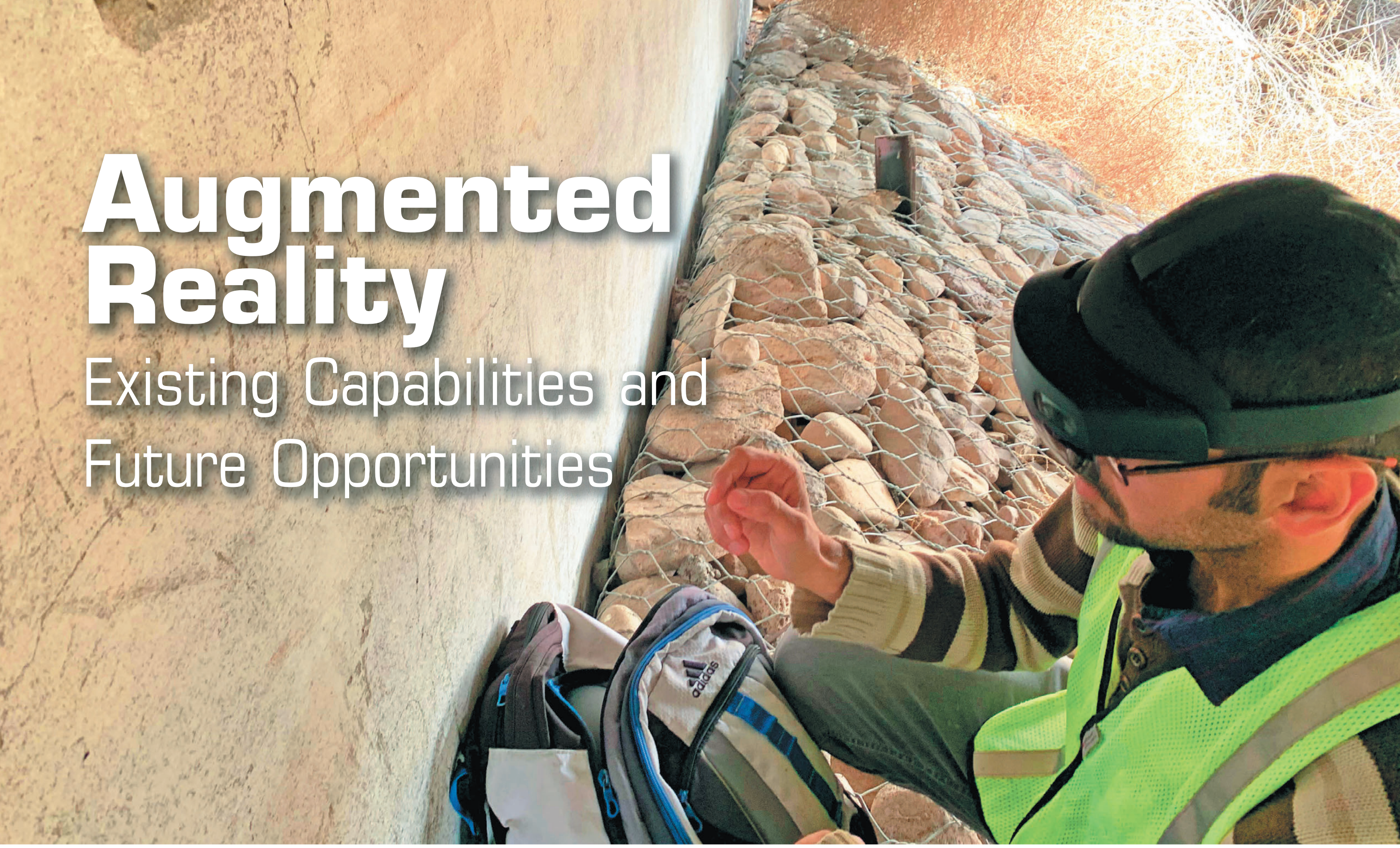
Augmented Reality

Existing Capabilities and Future Opportunities



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Augmented reality is changing how we look at the world around us and how we interface with devices that can aid human observation, quantification, recording, and maintenance tasks. It also is helping inspectors do their jobs more accurately—and quickly.

During the last decade, augmented reality has moved from research and gaming to business and industry—including infrastructure engineering and construction. Augmented reality mixes reality and virtual information in the field, which brings new opportunities to the infrastructure industry. This technology figures prominently in the future of social media and will bring virtual reality and augmented reality technologies together. It is timely to understand the following:

- Where and when augmented reality was designed, developed, and offered in its early days;
- What augmented reality is and why it is here to stay;
- What augmented reality hardware and software is available;
- What current applications exist in areas related to the infrastructure side of human–infrastructure interfaces; and
- Which gaps recognized from preliminary results are being investigated.

The Early Days of Augmented Reality

The engineering community started adopting head-mounted augmented reality devices in the 1960s (*1*). These early holographic experiences had limited resolution, brightness, and field of view. The following three decades focused on addressing visualization problems and, in 1997, a survey summarized the technology's development challenges (*2*). In the last two decades, augmented reality ecosystems have matured enough to generate applications for infrastructure, especially in the areas of construction and inspection.

What Is Augmented Reality?

In essence, augmented reality superimposes digital or computer-generated content over the existing real-world environment (*3*). This technology integrates virtual objects with real objects in real time (*2*). The concepts of augmented reality and virtual reality are related, and the exploration of the two definitions together makes it easier to understand both concepts (*4*). While virtual reality leads the transformation from the real world to a new virtual world by blocking users' view from the physical environment, augmented reality enhances human experience of the real world by overlaying virtual information upon imagery of the physical environment. In the last decade, the augmented reality industry introduced lightweight devices, including a see-through headset that enabled eye tracking, hand gestures, voice commands, and mapping capabilities (*5*). These abilities enable this technology to be used in a wide range of activities in the infrastructure engineering industry.

Augmented Reality Hardware and Software

Augmented reality hardware is classifiable into three main categories: stationary, handheld portable, and head-mounted device (*6*). Table 1 compares the advantages and disadvantages of different hardware. Although the cost of today's headsets are high and computational limitations remain, powerful, affordable headsets will become available in the near future (*6*). After overcoming inherent limitations, headsets will provide considerable benefits for human–computer–infrastructure interactions and will surpass handheld or stationary devices (*7*).

Two creation platforms—Unreal and Unity—are used to develop applications for headsets with integrated computing capabilities. Although Unreal is a new engine for creating augmented reality tools, master application designers traditionally developed sophisticated applications using the Unity game engine platform (*8*).

Augmented reality developers use the C Sharp programming language, and the main contribution of researchers is the programming of new applications in response to requests from infrastructure owners or managers. In this context, conventional programming skills may not be sufficient to develop new applications that infrastructure owners require because of C Sharp limitations for Unity projects. Augmented reality applications and packages on different systems also need to be compatible and updated regularly.

Augmented Reality Applications

SMART MANAGEMENT OF INFRASTRUCTURE

Even as early as the 1990s, early augmented reality systems used during construction could find rebar located inside structures and overlaid 3-D frames (*9*). These prototypes identified challenges related to field implementation in real structures and the areas of additional research for implementation. Technical advancements in the last decade have enabled new uses of augmented reality to enhance infrastructure projects, such as

- Simulating designed structures before their construction,
- Providing virtual site visits,
- Offering effective means for online interaction,
- Developing new teaching strategies (*10*), and
- Evaluating the dimensional and geometric positions of physical objects (*11*).

The following section summarizes current advances in augmented reality research conducted in the context of the smart

TABLE 1 Types of Augmented Reality Hardware

Augmented Reality Hardware	Stationary	Handheld Portable	Head-Mounted Device
Devices	**PCs and Servers**	**Smartphones and Tablets**	**Augmented Reality Headset**
Hardware Configuration			
Advantages	High-Processing Capacity	Mobility and Low Cost	Mobility, Hands-Free Capability, and 3-D Image Projection
Disadvantages	2-D Screen and Low Mobility	2-D Screen, Requires Hand Support	High-Cost, Low-Processing Capacity, and Limited Field of View

management of infrastructure. The applications discussed are not all-inclusive, but they present a summary of the most recent capabilities intended to transform the interfaces between humans in the field and the infrastructure they manage.

TIME MACHINE MEASURE APPLICATION

The time machine measure application enables humans to save and restore a virtual representation of physical objects in the real-world environment over time. The augmented reality user can measure and track changes in a physical object based on color-coded virtual representations of the real environment recorded at specific times. The user is aware of both the status of reality and the damage pattern progression over time, which is applicable to structural health monitoring. The application can inform inspectors of changes that may not be obvious to the human eye—or memory—as well as changes that go unnoticed. As shown in Figure 1, augmented reality provides a way of recording changes to the real structure over time that was not previously possible (*12*).

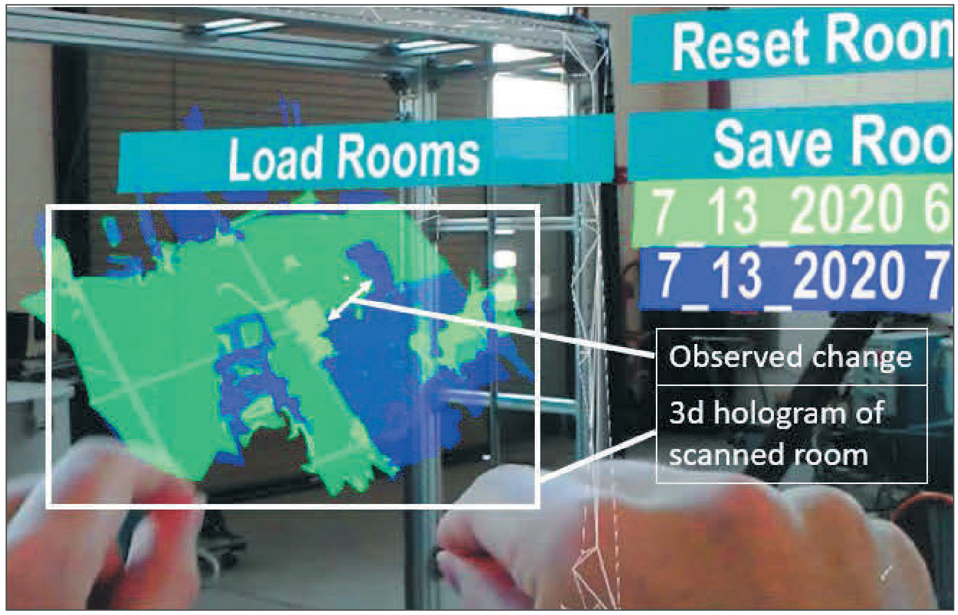
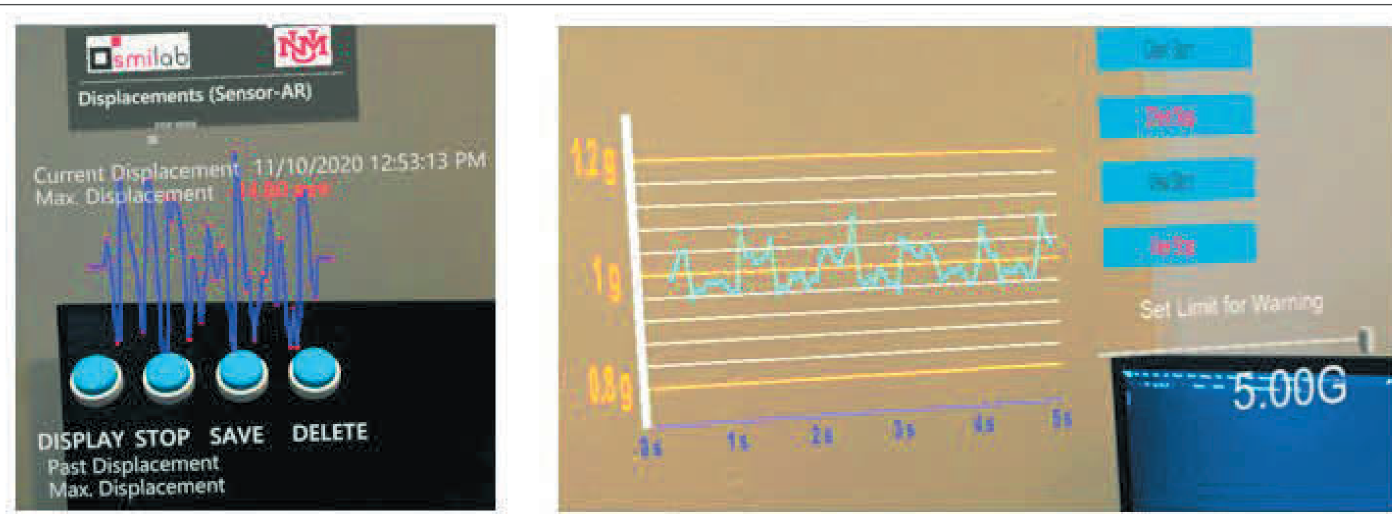


FIGURE 1 The time machine measure app shows the movement of the structure. (Courtesy of Elijah Wyckoff)

INTEGRATED SENSORS

Augmented reality headsets are capable of connecting to sensors and displaying sensor data in real time (*13*). This implementation overlays sensor measurements in real time. The first augmented reality headset with integrated sensors was developed and supported by the U.S. Air Force Research Laboratory and the New Mexico Consortium, a nonprofit corporation to facilitate research and comprised of three New Mexico universities. Augmented reality developers programmed an algorithm calculating and showing the reference-free sensor displacement to the user in real time (Figure 2a) (*14*). Another application was created to plot live vibration levels in an augmented reality headset (*15*). The headset, which was connected to a smart sensor over Wi-Fi, sent acceleration values that were plotted and visible in the user's view (Figure 2b). This allows the



(a) (b)

FIGURE 2 Sensor data visualization in augmented reality reveals (*a*) displacements and (*b*) accelerations. (Courtesy of Elijah Wyckoff)

human to maintain awareness of the real response of the dynamic structure while also monitoring data to make informed decisions.

ROBOT CONTROL

Robot automation with augmented reality technology is being implemented for sensor placement and feedback. By designating an augmented reality application for robot arm control, an interface that includes the camera view from the robot's perspective was developed, as were commands for sensor pick-and-place sequences, as demonstrated in Figure 3. Mode shapes and finite element models also can be included in the interface to inform the human of expected results and the correct location for sensor placement (*16*). These capabilities are particularly beneficial for the construction of hard-to-access parts of structures where traditional construction methods are costly and time consuming. Robots can be used to inspect infrastructure in places where human safety may be at risk. The U.S. Department of Transportation University Transportation Consortium of South–Central States (Tran-SET), a collaborative partnership including nine major institutions and two community colleges in five states (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas), has supported several projects that implement technology for the construction and maintenance of infrastructure. Brutus is a robot that can test the properties of mechanical surfaces using multiple taps. Operating Brutus frees the augmented reality user from a handheld controller.

HUMAN–INFRASTRUCTURE INTERFACES

The Transportation Research Board (TRB) is supporting projects related to augmented reality and prioritizing the exploration of human–machine interfaces to advance the integration of computer vision with augmented reality and improve inspectors' perception in the field. These Innovations Deserving Exploratory Analysis (IDEA) projects[1] include

- National Cooperative Highway Research Program (NCHRP) Project 20-30/IDEA 223, "Fatigue Crack Inspection Using Computer Vision and Augmented Reality" and
- Rail Safety IDEA Project 43, "Augmenting Reality for Safer Inspections of Railroad Infrastructure and Operations".

With the support of TRB, researchers recently developed various advanced human–structure interface algorithms and provided their connections with augmented reality for a multidisciplinary effort involving the FRA on a Class I railroad project in which augmented reality aided industry collaborators inspecting a railroad bridge in Chicago, Illinois (*17*). This new approach has the potential to transform bridge inspections.

DETECTING FATIGUE CRACKS

Fatigue cracks in steel structures are significant because they are miniscule—which makes them hard to identify—and they propagate rapidly. Fatigue crack detector augmented reality software enables inspectors to find these cracks by analyzing the parts of the steel structure prone to cracking and showing the crack's location to inspectors in close to real time. The menu for this software, shown in Figure 4, provides a virtual view developed for steel fatigue crack detection. In collaboration with the University of Kansas and the University of New Mexico, a new approach used innovative software

[1] For more about NCHRP Project 20-30/IDEA 223, see https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5057. For more about Rail Safety IDEA Project 43, see https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5081.

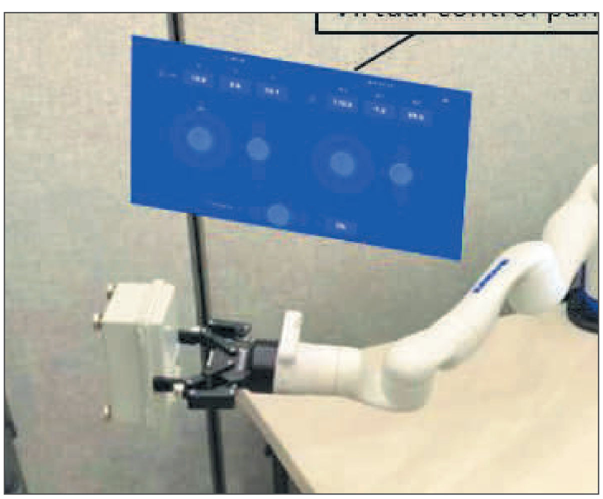


FIGURE 3 A robot arm controlled by augmented reality places a sensor box on a structure. (Courtesy of Elijah Wyckoff.)

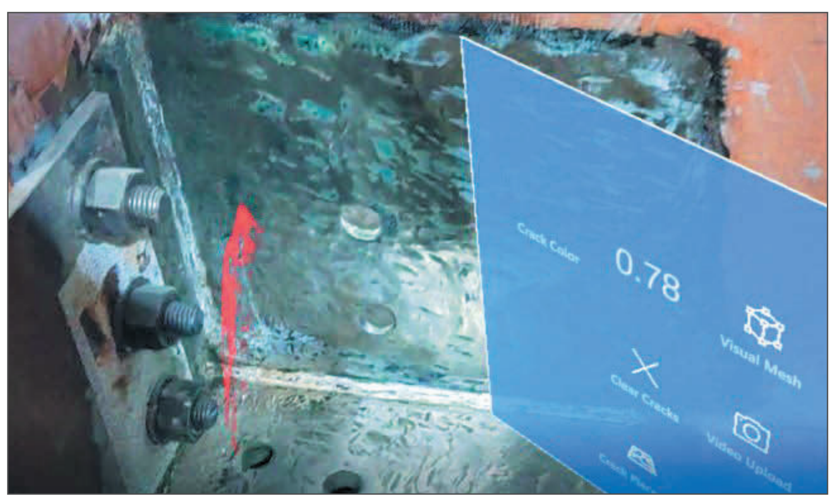


FIGURE 4 An augmented reality steel crack detection tool places a red mark—the virtual indicator—to show a crack's location in the steel structure's joint. The fatigue crack detection software also displays a virtual menu to facilitate field inspection.

developed to integrate computer vision in augmented reality so that inspectors could find fatigue cracks while wearing a headset. This research was developed as part of NCHRP Project 20-30/IDEA 223.

CHARACTERIZING CONCRETE CRACKS

Several studies integrated image processing for concrete crack detection and human inspection using the augmented reality platform. In these studies, headsets were connected to stationary devices via physical connections or the Internet. Image processing was performed in the stationary processing devices, and the processed images were sent to an augmented reality headset for localization and visualization (in which the headset locates the crack and shows the location to the user). Recently, Tran-SET and the New Mexico Department of Transportation funded a project at the University of New Mexico aimed at creating augmented reality crack detection and characterization tools for real-world inspections. This study eliminated the dependence of augmented reality crack characterization methods on external processors. The technology's software addresses one of the challenges in image-based crack detection methodologies: locating cracks in the field from images of the detected cracks on a computer screen. Augmented reality headsets can be used to transform these manual tasks to an automatic process and to project the computer analysis results in front of the user's eyes in real time.

The Future

Successful integration of human–infrastructure interfaces already has been achieved in a variety of structural contexts that include, but are not limited to

- Structural quantification (such as length, area, and size measurement),
- Visualization of quantification results or external processor data such as sensor data,
- New interfaces with mechanical tools controlled and managed by humans observing augmented reality virtual quantities overlaid on relevant physical objects, and
- Real-time artificial intelligence implementation with augmented reality that offers potential empowerment of infrastructure operators and inspectors.

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Bridge inspectors in New Mexico compared crack measurement methods to explore the practicality of using augmented reality for bridge management. Using existing methods, inspectors measured crack width at a given location with a thin, handheld plastic gauge and visual observation. Using advances in the technology, inspectors can put on an augmented reality headset to examine a given area of the surface through augmented eyes.

Although augmented reality has many benefits for structural inspection and assists inspectors in improving their inspection quality, there are still some issues that must be addressed in future research. The most significant of these involve head-mounted devices because they have limited analysis capacity, insufficient battery capacity, and are heavy enough that they may cause fatigue for inspectors performing lengthy inspections.

The future of augmented reality for enabling a new infrastructure industry, changing workforce management strategies, and even developing new infrastructure policies corresponds to future technological advances in software and hardware, such as

- Decreasing headset weight, potentially by separating batteries and computational units from head-mounted devices;
- Advancing holographic lenses so that they provide a better blend of virtual objects with real elements and eventually improve the visualization experience;
- Enhancing lenses or enabling higher contrast to permit more efficient data capture in the field (the impaired view from current headsets in direct sunlight is a barrier to application);
- Increasing the headsets' field of view to permit the user to have a better experience in the field, while not losing awareness of reality; and
- Increasing the head-mounted device's analysis capacity and improving the technology to provide faster analysis, gain independence from external processors, determine relative displacement, and solve registration problems that occur when unregistered files in useful libraries make those libraries undeployable in augmented reality headsets.

Further augmented reality integration with infrastructure depends on technical advances in its hardware and software and the early teaming of researchers and infrastructure stakeholders to identify gaps for implementation and suggest priorities for bridging those gaps. Both entry-level and experienced members of the workforce can benefit from a new work environment that will improve their quality of life, as well as advance their profession.

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VOLUNTEER VOICES

"If I could go back in time, I would change two things that would have fundamentally altered American transportation. First, I would plan the Interstate system and other long-distance routes to go toward and around our cities, rather than carving through them. This approach would be less destructive and far less expensive to taxpayers. Second, I would change how we develop our cities and suburbs. The current widespread adoption of single-use zoning separates all the different types of land uses. This requires extensive parking lots and more driving and makes walking and biking more difficult and dangerous. In contrast, establishing zoning rules based on New Urbanism concepts allows for development that mixes land-use types and a public space design that is attractive and compact and, therefore, walkable. We would all have to drive far less than we do in today's suburbs, which would lessen public expenditures in wide roads."

—BRENT SWEGER
Quality Assurance Branch Manager
Kentucky Transportation Cabinet, Frankfort