Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Augmented Reality Enhancing the Inspections of Transportation Infrastructure: Research, Education, and Industry Implementation

Project No. 18STUNM03

Lead University: University of New Mexico

Final Report

August 2019

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Acknowledgements

The authors want to thank the following collaborators who supported this research: New Mexico Department of Transportation (NMDOT), City of Albuquerque, Center for Advanced Research and Computing (UNM), Microsoft, Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), Air Force Research Laboratory (AFRL), Central New Mexico Community College (CNM), Native American Community Academy (NACA), Canadian National Railway (CN), BNSF Railway, Union Pacific Railroad (UP), Los Alamos County (LAC), Association of American Railroads (AAR), and Federal Railway Administration (FRA.)

TECHNICAL DOCUMENTATION PAGE

1. Project No. 18STUNM03	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Augmented Reality Enhancing the Inspections of Transportation Infrastructure: Research, Education, and Industry Implementation.	**5. Report Date** Apr. 2019 **6. Performing Organization Code**
7. Author(s) PI: Fernando Moreu https://orcid.org/0000-0002-7105-7843 Co-PI: Chris Lippitt https://orcid.org/0000-0001-7979-7857 GRA: Dilendra Maharjan https://orcid.org/0000-0001-6365-072X GRA: Marlon Aguero https://orcid.org/0000-0001-7739-1378 GRA: Xinxing Yuan https://orcid.org/0000-0003-0163-602X	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Transportation Consortium of South-Central States (Tran-SET) University Transportation Center for Region 6 3319 Patrick F. Taylor Hall, Louisiana State University, Baton Rouge, LA 70803	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** 69A3551747106
12. Sponsoring Agency Name and Address United States of America Department of Transportation Research and Innovative Technology Administration	**13. Type of Report and Period Covered** Final Research Report Mar. 2018 – Mar. 2019 **14. Sponsoring Agency Code**

15. Supplementary Notes

Report uploaded and accessible at Tran-SET's website (http://transet.lsu.edu/).

16. Abstract

Transportation infrastructure needs continuous monitoring that is conducted by field inspectors regularly in the field. Currently, infrastructure inspectors climb, measure, and photograph structures annually to inform repair needs and prioritize decisions. In order to promote and accelerate early learner's expertise in decision-making capabilities during infrastructure inspections, this research project developed various software applications using augmented reality (AR) as an inspection tool for bridges and bridge management, more specifically. By objectively quantifying infrastructure field inspections, inspectors can make more accurate field assessments and managers can make better-informed decisions. This project collaborated with stakeholders, national laboratories, DOT agencies such as NCHRP and NMDOT, and local owners like the City of Albuquerque, to inform the needs of AR for field inspections. The results of this study summarized the current limitations of visual inspections from the perspective of the various owners, as well as pilot developments of AR applications and their benchmarked accuracy in comparison with visual methods. The education and training aspect of this project included teaching and exposing AR to high school students, community college students, undergraduate students, and graduate students, as well as industry (bridge inspectors). This research project's outcome includes a webinar free to access in the NCHRP national website on this topic. The conclusion of this research is that AR can be an effective tool and that industry is interested in specific programming of AR software that matches their bridge management needs.

17. Key Words	**18. Distribution Statement**
Bridge Management; Augmented Reality; Wireless Smart Sensors; Structural Health Monitoring; Education and Training.	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	44	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AAR	Association of American Railroads
AFRL	Airforce Research Laboratory
AI	Artificial Intelligence
AR	Augmented Reality
ASCE	American Society of Civil Engineers
BNSF	Burlington Northern Santa Fe Railway
CARC	Center for Advanced Research and Computing
CN	Canadian National Railway
CNM	Central New Mexico Community College
FRA	Federal Railway Administration
ITS	Intelligent Transportation Systems
IWSHM	International Workshop of Structural Health Monitoring
LAC	Los Alamos County
LANL	Los Alamos National Laboratory
LEWIS	Low-Cost Efficient Wireless Intelligent Sensor
LEWIS2	Low-Cost Efficient Wireless Intelligent Sensor (Version 2)
LVDT	Linear Variable Differential Transducer
MRR	Maintenance, Repair, and Replacement
NACA	Native American Community Academy
NMDOT	New Mexico Department of Transportation
SHM	Structural Health Monitoring
SNL	Sandia National Laboratories
SMILab	Smart Management of Infrastructure Laboratory
SOE	School of Engineering
TTCI	Transportation Technology Center, Inc.
UAS	Unmanned Aerial System
UNM	University of New Mexico
UP	Union Pacific
VR	Virtual Reality
WS	Wireless Sensor

WSS	Wireless Smart Sensors

EXECUTIVE SUMMARY

More human centered technology that can help inspectors to collect data to monitor the health of bridges and critical transportation infrastructure systems are critically needed. This project report summarizes the results of development of various Augmented Reality (AR) solutions programming novel interfaces between humans and infrastructure that can be cost-effectively developed and used by transportation agencies, and more particularly owners of transportation infrastructure. The input from industry at the start of this project directed the identification, selection, development, and testing of augmented reality in scenarios that they need for their daily operations and managerial decisions. This research was developed with industry (infrastructure owners and national laboratories) so the impact of AR has been benchmarked with current operations, such as accuracy, time, and safety. The exposure of students and inspectors to augmented reality provided researchers with data to evaluate the success in its implementation by the transportation industry, which are also summarized in this report.

This grant supported the development of AR applications generated by students enrolled in new classes, both in UNM, CNM, as well as under supervision by LANL and AFRL. The grant funded one UNM graduate student who developed new AR tools (HoloLens) enhancing infrastructure inspection and trained undergraduate students in AR. The resulting technology will be benchmarked with existing technologies in the implementation phase. A new class in CNM was developed to train CNM students on AR by contacting the UNM students using AR. By engaging in this research, STEM students developed their knowledge in the use of AR technologies and related them to bridge and infrastructure inspection. By collaborating with LANL, UNM students were able to collaborate with a different institution throughout the project. Another aspect of this project was the relationship of using AR as research, as part of one undergraduate class, and also the connection of programming AR in relation to current infrastructure inspection needs. More specifically, the undergraduate and graduate students involved in this research worked together with the owners of infrastructure to understand the challenges and opportunities related to innovation and practical applications. By participating in this project, the students were trained in railroad engineering, bridge inspections, industrial structures, augmented reality, electrical engineering, and data processing. Finally, this research in AR promoted workforce development in the earliest stages of education in transportation infrastructure management and maintenance.

This research was carried out in collaboration with the Center for Advanced Research and Computing (CARC) of UNM, the railroads in Region 6: Union Pacific (UP), Canadian National (CN), and Burlington Northern Santa Fe Railway (BNSF); the New Mexico Department of Transportation (NMDOT); the national laboratories in New Mexico (Los Alamos National Laboratory, Sandia National Laboratories, Airforce Research Laboratory); Central New Mexico Community College (CNM) and Native American Community Academy (NACA); the city of Albuquerque Center for Emergency Operations; Los Alamos County (LAC), Association of American Railroads (AAR), and Federal Railway Administration (FRA.)

In the spring and summer of 2019, the implementation through training and testing will be conducted.

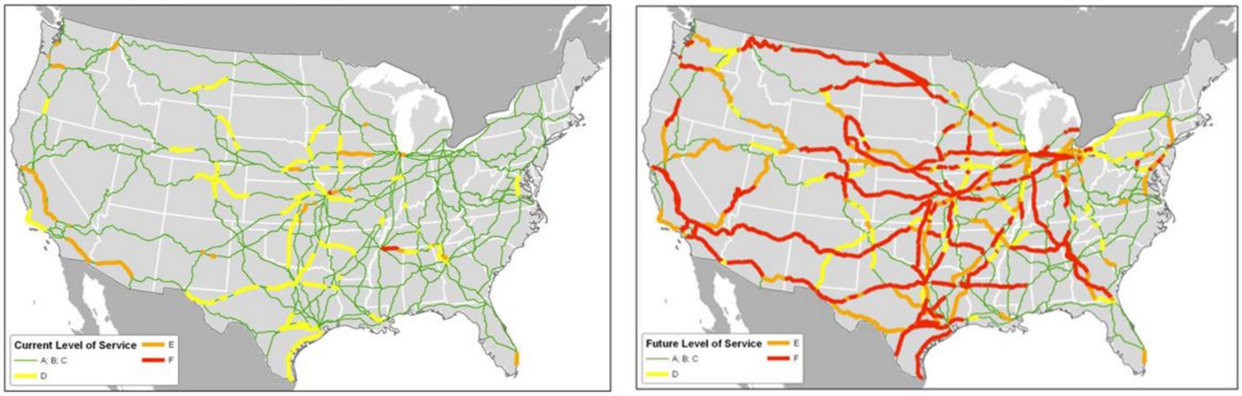
1. INTRODUCTION

North American infrastructure systems, including transportation networks, are increasingly decaying in terms of safety and capacity. Network demands are changing. Consequently, the cost of bridge repair and adaption for higher loads are increasing, surpassing available funds. There is limited data, however, about the decay of performance of these systems over time. Inspectors try to collect intelligent information in the field that informs their assessment, and their reports serve as the main source of information used by managers to make critical infrastructure decisions. However, infrastructure owners and managers are in need of more quantifiable information to improve their objectivity and the safety of inspectors. Field inspectors are expensive, sometimes work in conditions that are not safe, and provide subjective information. Current sensing approaches, however, are not collecting parameters that inform the decisions that need to be made based on those measurements. Not to mention the costs associated to instrumenting the inspections, which are not affordable by transportation infrastructure managers. Secondly, structural models are developed by academicians and research companies to better model responses, but those computational advances are not useful to current inspection needs. To overcome this problem, this research proposal designs a new approach between an interdisciplinary academic research team (civil engineering and geography), Los Alamos National Laboratory (LANL), the Canadian National (CN) railway *(1)* and BNSF *(2)*, owners of railway infrastructure, and the New Mexico Department of Transportation (NMDOT). This partnership will equip humans (inspectors) with machine capabilities to carry out their inspections more effectively using Augmented Reality (AR) approaches that can be used by transportation owners. This partnership will empower bridge inspectors to cost-effectively collect data. The participation of experts in infrastructure maintenance and sensing in the workshop stage of this proposal will allow students to get exposure to industry careers related to infrastructure management and maintenance using AR.

1.1. The Case of Railroad Bridge Infrastructure Maintenance and Bridge Inspectors

Today, freight transportation in North America is widely accepted to be the best in the world. Today, 40% of the US's freight tonnage is carried by railroads. Data from the Association of American Railroads (AAR) estimated the cost of infrastructure expansion that was needed to match the 2007-2035 estimated growth was $148 billion (in 2007 dollars) *(3-7)* (Figure 1). Enhancing the assessment of civil infrastructure has many challenges, as it requires a wide range of temporal and spatial resolution and extensive field validation, and there is a dearth of effective data collection approaches to inform decisions. To solve this problem this research team will enhance the inspector's ability to perform structural inspections using AR.

Currently, bridge inspection reports inform Maintenance, Repair, and Replacement (MRR) decisions within the entire network *(8)*. Bridge inspections are required annually since 2010 as part as the bridge management program *(9, 10)*. Bridge inspections take time, cost money, and are often conducted in risky environments with limited access by inspectors. In addition, two significant challenges affect bridge inspections today: (1) bridge inspectors need to visually evaluate all bridge structural elements and thereby are exposed to unsafe environments, and (2) visual observations without measurements cannot quantify defects and are in general subjective and depend on the experience of the inspector *(11, 12)*.



(a) (b)

Level of Service (LOS)	Means	Description
	Below Capacity	Can accommodate maintenance work and recover from incidents
	Near Capacity	Heavy train flow, moderate capacity to accommodate work
	At Capacity	Very heavy train flow
	Above Capacity	Unstable flow; service break-down conditions

Figure 1. Railroad corridor capacities level of service: (a) in 2007 and (b) in 2035 *(7)*.

1.2. Bridge Inspection Problems

Contemporary manual/visual inspection protocols for transportation infrastructure have a lot of room for improvement. Visual inspections contain an element of subjectivity and as a result the conclusions of different inspectors can be highly variable and depend on a variety of factors. The manual use of cameras, rulers, and notes to measure and document the size, severity and extent of damage is common practice. Section loss and scour damage is estimated in a visual manner leading to variations between inspection teams. To solve these problems, this project has developed a new, novel approach using AR to increase the technical ability of the inspector. A multi-disciplinary team from the University of New Mexico (UNM) partnered with the CN railway, NMDOT, and LANL to augment the human ability to measure the condition of the bridge using AR. The approach proposed by this multi-disciplinary team from UNM, with the strong support of infrastructure owners and national laboratories, guarantees the broader impact of this research was attained by not only developing new hardware and software not available to date, but also be sharing the proposed technology before, during, and after its development with infrastructure owners.

1.3. Augmented Reality as a Tool for Bridge Inspectors

This research implemented AR technology to improve the ability to perform bridge inspections. Our new AR application allows inspectors to more easily document structural inspections in a quantitative manner. Students funded with this support introduced AR to high schools and middle schools in New Mexico. By implementing the AR technology in the bridge inspection routines today, according to NMDOT, it is expected that the variability that exists in manual inspections between different inspectors and inspection teams will be reduced. This will be developed in the implementation phase with NMDOT. The implementation goal of this project is to take AR equipment and build the appropriate interface to enable the structural inspection of the future. The principal investigator (PI) will conduct a class on AR for high school students in the Summer Transportation Institute (STI) in 2019, which will include a competition with the high school students to inspect different crack lengths with AR.

1.4. Future Funding Proposals on AR for Infrastructure Inspection

The results of this project show that AR has a significant impact in facilitating the monitoring and assessment of infrastructure systems. The results of this research show prototypes that benefit the understanding of AR applications to transportation operations and budgets nationwide, and internationally. New proposals using the preliminary data will be submitted to the USDOT, Federal Railway Administration (FRA), National Science Foundation (NSF) *(13)*, and USDOT pool funds. Successful development of the proposed technology can also provide a basis to increase capacity of transportation networks while reducing expenses as a result of better understanding performance. The strong partnership with a Class I railroad will guarantee the high impact of this research *(14, 15)* (Figure 2). The collaboration with LANL allowed UNM students to collaborate with a different institution throughout the project, broadening the impact for regional students. The students will receive training by visiting the railroad bridges in the implementation phase (which will serve to increase their training and preparation in the engineering workforce. The active participation of the PI and Co-PIs will support student exposure to research that is strongly tied to innovation and entrepreneurship. At least one patent has been disclosed by the students in the UNM patent office related to AR for infrastructure inspection.

Figure 2. Measuring railroad bridge displacements in the field *(14, 15)*.

2. OBJECTIVES

The objectives of this research were divided in two phases: research phase and implementation phase.

2.1. Research Phase

The technical objectives of this research included:

1. Contact LAC, City of Albuquerque, railroads, USDOT, and National Laboratories. Researchers collected their needs and suggestions for the use of AR for transportation infrastructure inspections.
2. In collaboration with LANL, researchers elaborated a pilot research program developing various applications that were programmed and tested in laboratory settings.
3. Researchers programed, tested, and checked the new AR applications to augment field measurements using input from objectives 1 and 2.
4. Researchers involved both students and industry in 3).
5. As part of the research objectives, researchers also shared AR applications with middle schools and high schools, industry, and owners.
6. At the end of the project, the researchers conducted one workshop with NMDOT. The objectives of that workshop are to summarize their achievements and to prepare the implementation phase of the project.

By the end of this project, researchers have finished all the research objectives outlined above.

2.2. Implementation Phase

The results of this research have been shown to infrastructure owners both in a webinar and in the workshop. Infrastructure owners have expressed their interest to commit resources to the further development of AR for inspection of transportation infrastructure, more specifically, NMDOT. The following implementation steps have been followed:

1. Development of software to use AR for infrastructure inspections, demonstrated in laboratory settings to NMDOT during the workshop.
2. Benchmarking of the results of using this software comparing benefits for field implementation: safety, accuracy, and time (crack measurement app, shown to NMDOT.)
3. Teaching of AR to high school students, and undergraduate students with STEM classes (summer 2019.)
4. Trimester reports to panel review to receive feedback in the technology.
5. Demonstration at international conferences including the annual transportation research board (TRB) meeting in Washington, D.C.; Engineering Mechanics Institute (EMI) of the American Society of Civil Engineers (ASCE); international students in Summer School in Smart Structures (Asian-Pacific-European Summer School [APESS] in La Sapienza, Rome, Italy); and the international workshop on structural health monitoring (IWSHM) in Stanford, California.

The proposed research equipment and analysis methods provided evidence that with AR, inspectors increase their ability to quantify bridge conditions faster, more accurate, and more safely. Results of the project were presented to industry, including, but not limited to: Federal Railway Administration (FRA), US Department of Transportation (USDOT), and NMDOT. In the implementation phase the objective was to identify the needs of industry for a practical implementation of AR, so that the further development of AR applications addressed those. The final contribution of the implementation was that AR applications were developed not only to address structural inspections from a precision standpoint, but also in areas of demand of industry and owners from their day-to-day operations.

3. LITERATURE REVIEW

North American infrastructure is crumbling and has already exceeded in many cases its 50 years of expected life, in particularly, critical infrastructure built in the 50s and 60s. The role of structural inspectors is increasingly important as bridges, dams, and nuclear power plants require repairs and replacement before they fail. During inspections, infrastructure inspectors look for changes in physical characteristics *(1, 2)*. This informs their assessment of the safety of the structure. The collection of structural data, including measurement of damages, such as cracks, spalling (area), and volumes, is carried out based on the experience of the inspector. The collection and sharing of data by inspectors inform decision-makers, hence owners rely on experienced inspectors. Experienced inspectors prioritize the amount of information that needs to be collected due to limits in time and access to the structural parameters of interest. The use of technology can address the human limitations in the profession of infrastructure inspections. The 2025 vision of the American Society of Civil Engineers (ASCE) predicts "In 2025, intelligent infrastructure (embedded sensors and real-time onboard diagnostics) have led to this transformation of rapidly advancing and adapting high-value technologies in the life of a structure. Real-time monitoring, sensing, data acquisition, storage, and modeling have greatly enhanced the prediction time leading to informed decisions *(16)*." Further, this report states that engineers will be "relying on and leveraging real-time access to living databases, sensors, diagnostic tools, and other advanced technologies to ensure informed decisions are made" (see Figure 3). Transforming about the profession of infrastructure inspectors through technology plays a fundamental role in the creation of future professions and jobs, generates new interactions between humans and machines, and informs consumers about the impact of technology to health, economy, safety, comfort, and quality of life.

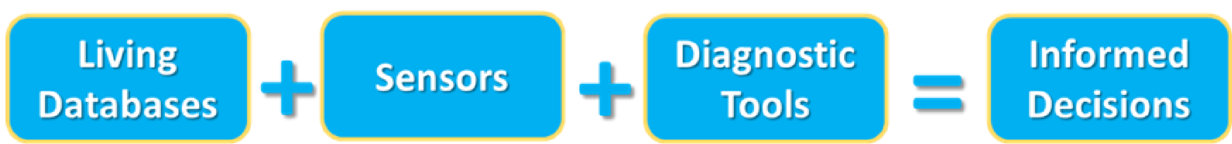


Figure 3. ASCE 2025 Vision *(16)*.

3.1. Environment Perception

Using machines or computers to perceive the surrounding environment brings exciting possibilities in the area of cyber-human interaction. Recent research *(17, 18)* highlights the 3-Dimensional User Interface (3DUI) for immersive interaction with the virtually reconstructed surrounding environment. The ability to select, modify and refine the virtual environment could be the new frontier in environment perception in Cyber-Human Interface.

The concept of a smart environment is not new. Past research *(19)* has pointed out the main areas of Artificial Intelligence for smart environments with four main components: Pervasive-Ubiquitous computing, Human-Computer Interfaces, sensors and Networks come together to form what the author refers to as Ambient Intelligence (AmI). Such a network would have computational capabilities that can link perception through sensors with actuation based on human decisions. AmI emphasizes building non-intrusive digital environment that supports the daily lives of people. How we perceive the environment to make intelligent decisions is evolving. Therefore, the way humans are perceiving the surrounding environment is changing with more computer-assisted perception being developed with human-centered interactions.

3.2. Human Centered Design

The ISO 9241-210 standard defines human-centered design as "an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" *(20)*. The control of human-centered design puts humans at the center of the loop as depicted in the research by Garcia Lopez *(21)*. The issue of computers assisting humans is most used in creating intelligent environments for the elderly population and people with disabilities. In research by Alexandra Queirós *(22)*, a broader term for accessibility is defined in conjunction with usability. This report also highlights the technology requirement to be user-friendly, human centric independent of individual abilities and characteristic. Human Centered Computing (HCC) is a system that leverages the power of computer to enhance human accessibility to surrounding environments.

The works being prioritized in human-centered design is the development of interfaces that can enhance the experience of users. J. Hollan et al. *(23)* proposed the radical concept of distributed cognition in the field of Human Computer interaction. The paper proposes designing distributed cognition for complex networked worlds of information and computer-mediated interactions. Ramesh Jain *(24)* talks about using multimodal dynamic data from disparate source and organizing for user experience.

A multimodal data refers to interface tools for users to access the input/output of data using more than one modality. Natural ways of communication such as voice recognition and hand gestures would be multimodal communication in an HCC environment. The multimedia perspective of HCC is described by Jaimes et al. *(25)* incorporating the aspects of multimedia interaction such as voice, images, text, location data, proximity sensor. The paper highlights the issues of integration human spaces, ubiquitous devices, virtual environments and art. Recently vision-based hand gesture recognition for interaction with computers has seen an increased interest from researchers as a practical way of natural interaction *(26)*. This will create an immersive experience to the users while interacting with computers.

3.3. Human-Machine Interfaces

Machines help human interface with their environment by improving accuracy and quality of life. Researchers use neurophysiological signals to develop neuro-prosthetics increasing brain-machine interfaces, augmenting the presence and interaction of injured individuals with their environment *(27, 28)*. Another type of control system known as myoelectric control systems (MCS) were used to develop intuitive interfaces to assist amputees or disabled people control prosthetics based on muscle contraction *(29, 30)*. Human Machine Interfaces (HMI) have also been explored in the area of sensory substitution for humans to replace lost sensory ability such as touch, sight and vestibular function *(31)*. The study and research of human perception enabled by computer manipulation can change and overcome current barriers to peoples' lives and health.

The symbiotic relationship between human and machine can enhance safety and productivity in next generation manufacturing. Researchers demonstrated various mobile as well as virtual reality applications to technologically assist human workers in a factory *(32)*. The safety framework for human robot interaction has been discussed *(33)* emphasizing safety requirements such as robots working in a controlled space where robots and humans share a common workspace. The movement of robots should be easily predicted by humans to avoid collisions with humans in the workspace. With the advent of machine learning and advanced computational tools, human-machine interfaces based on predictive models have been developed to alert car drivers of accident risk *(34)*.

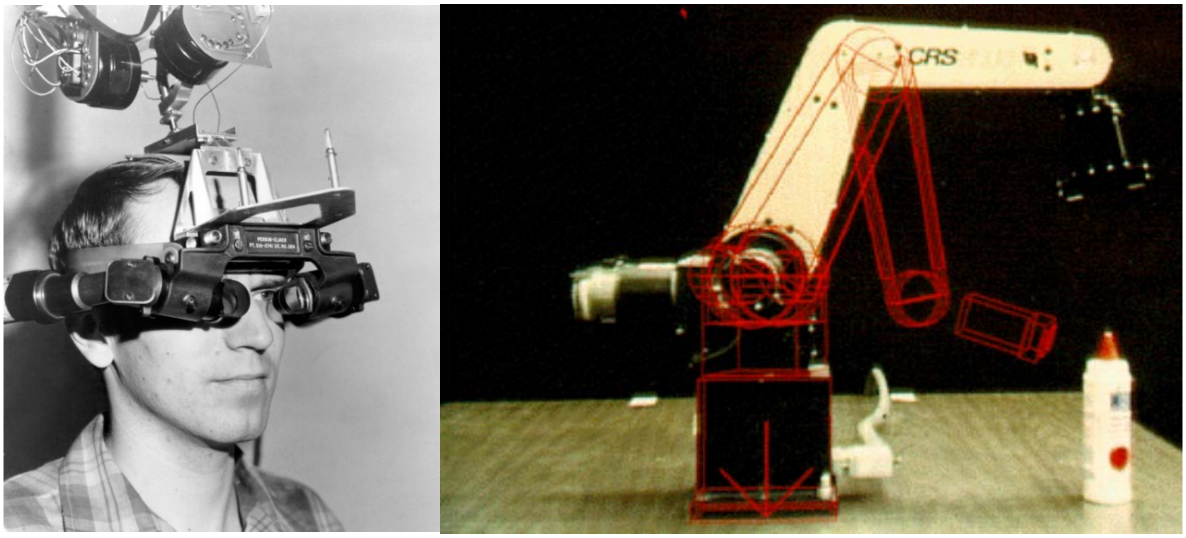
The human eye gaze location along with proximity sensor data is used to identify real time accident risks. The protocol of establishing interface with computers is gaining interest as the we become more open to use machines to do our day to day decisions. Researchers *(35, 36)* predict that Non-Verbal Communication (NVC) with computers such as eye movement, gaze, gesture operated VR and AR head-sets would be of value in future. Natural User Interfaces (NUI) that engages the user for immersive experience is one key area for future research. Past research *(37)* has also focused on implementing interface of robots with Augmented Reality spatial capture of the remote location.

3.4. Human Virtual-Environment Interfaces

By leveraging the power of cloud computing and artificial intelligence, the technology industry is developing virtual assistants such as Google Assistant, Alexa, Siri, and Cortana. Most of these applications are voice-controlled and lack fundamental natural communication skills such as gestures and body movements. Researchers *(38, 39)* have studied behavior changes due to the effect of using virtual environments. Augmented and virtual realities are also being used as psychological tools to change social interactions in the real world as well as social disorders such as panic disorder, post-traumatic stress disorder and phobias *(40-42)*. Building a virtual assistant, which would be a representation of one's self that is able to learn from you and fulfill your needs, can impact your health and well-being positively.

3.5. Augmented Reality

Augmented Reality (AR) refers to an enriched real world with a complimenting virtual world. In the case of Virtual Reality (VR), the real world is replaced by virtual objects and systems. By contrast, augmented reality enhances the real world by anchoring virtual information into it. The beginnings of AR date to the 1960's where head-mounted displays were used to present 3D graphics *(43)*. Such early inventions had problems with resolution, brightness and field of view *(44)* (Figure 4). A 1997 survey of augmented reality provided the field's uses, challenges and developments *(45)*. Since then, AR ecosystems have provided applications in various fields, including construction, structural inspection, evaluation and renovation. In 1996, an AR system had been developed that showed the location of columns behind a finished wall, showed the location of re-bars inside one of the columns, and that performed structural analysis of the column *(46)*. In 1999, a similar AR testbed system was used to address spaceframe construction *(47)*. These systems focused on demonstrating the potential of AR's X-Ray vision with a lab-based approach. However, it was neither transferable to a construction job site nor could it be used for real-time on-site applications. Additionally, challenges related to occlusion were experienced with the early age devices. Occlusion, otherwise known as obstruction, of real objects by virtual ones was not possible in conventional optical see-through displays. Such problems have been overcome by more recent technical advancements.



(a) **(b)**

Figure 4. Augmented Reality Past Developments; (a) Head-mounted 3D display *(27)*; (b) robotics and human interaction *(43, 44)*.

Recent advancements have shown particular promise for measurement. For example, an AR camera (ARCam) has been successfully used to inspect the column anchor bolt positions before installing a steel column and to assess its plumbness after installation *(48)*. The ARCam demonstrated time-related advantages when compared to a conventional total station, thus increasing productivity and reducing costs. Additionally, measurement precision was found to comply with standard tolerances. However, this system was only lab-based and non-transferable to the field. Further advancements were subsequently made in the augmented reality industry introducing devices like the Google glass, Moverio smart glasses and the current, Microsoft HoloLens *(49)* (Figure 5).

(a) **(b)**

Figure 5. HoloLens from Microsoft: (a) Version 1 *(49)*; (b) Version 2 *(36)*.

4. METHODOLOGY

4.1. Augmented Reality

4.1.1. State of the Art: Microsoft HoloLens

This research project will employ the Microsoft Holographic lens, more popularly known as HoloLens. HoloLens holds the capabilities of tracking eye movements, listening to voice commands, and following hand gestures *(49, 50)*. It consists of a Holographic Processing Unit (HPU) that creates a 3-D model of the surrounding environment. For this, it uses data generated by an inertial measurement unit, four spatial-mapping cameras, and a depth camera *(51)*. To sense the user's movements in a real-world environment, a number of advanced sensors are provided in the HoloLens. It uses this information, with layers of colored glass, to create images you can interact with or investigate from different angles *(52)*. Figure 6 shows a view of HoloLens 1 *(53)*.

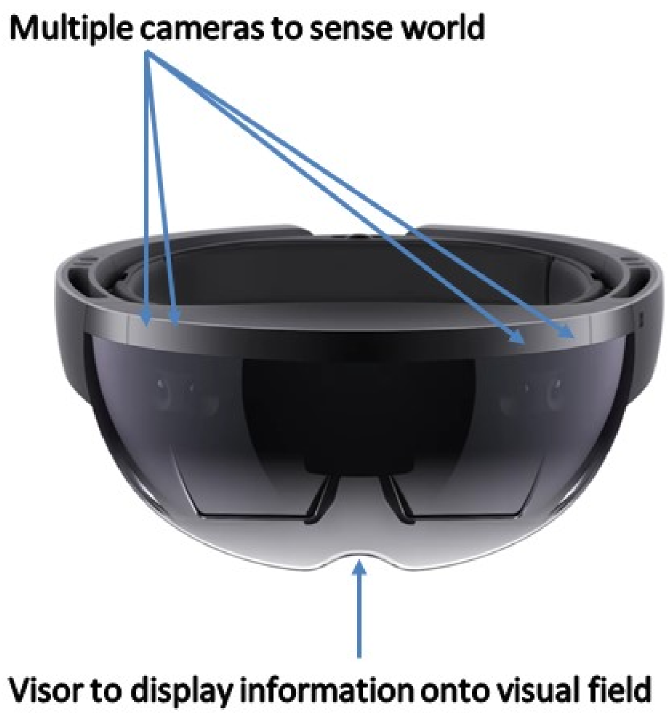


Figure 6. HoloLens 1 hardware *(49)*.

The capabilities of HoloLens are summarized in Table 1 *(53)*, separated in Human Understanding, Input/output commands, and connectivity and network. The research team has built from the basic interface various applications that enable the augmentation of inspectors in the field. Table 2 shows the main components of HoloLens Hardware, as shown in Figure 7.

Table 1. HoloLens human-computer interface *(53)*.

Category	**Feature**
Human Understanding	Spatial sound Gaze tracking Gesture input Voice support
Input/Output	Built-in External speakers 3.5mm Audio jack Volume up/down Brightness up/down Power button Battery status LEDs
Connectivity & Network	Wi-Fi 802.11ac Bluetooth 4.1 LE Micro-USB 2.0

Table 2. HoloLens hardware main components *(54)*.

Component	**Number**
Inertial Measurement Unit	1
Environment Understanding Cameras	4
Microphones	4
Ambient Light Sensor	1
Depth Camera	1

Figure 7. HoloLens Hardware Components *(54)*.

The software and hardware capabilities are summarized in Figure 8. Developers should use Windows 10 PC, with Visual Studio 2015 and Unity as the main requirements.

Table 3. HoloLens software and hardware capabilities *(53)*.

Component	Capability
Processor	Custom Microsoft Holographic Processing Unit HPU 1.0 Intel 32-bit architecture
Memory	2GB RAM 64GB Flash Storage
Weight	579g (1.2lbs)
Camera	2.4 MP photo 1.1 MP HD video Video Speed 30 FPS
Operating System	Windows 10 with Windows Store
Power	Battery Life 2-3 hours active use Up to 2 weeks standby time Fully functional when charging Passive cooling (no fans)

Figure 8. Software and Hardware Capabilities *(53)*.

The main interaction between the machine and the human is through the vision of the information through the optics enabled by Microsoft HoloLens (Figure 9). The summary of the new enabled holographic experience of the inspector is summarized in Table 4. The inspectors will augment their understanding of the structure through the visualization enabled by the new software.

Figure 9. Optics display of HoloLens for the Inspector *(53)*.

Table 4. Optical enabled interface with HoloLens *(53)*.

Feature
See-through holographic lenses (waveguides)
2x HD 16:9 light engines
Automatic pupillary distance calibration
Holographic Resolution: 2.3M total light points
Holographic Density: >2.5k radians (light points per radian)

4.1.2. Augmented Inspections Through Programming and Testing

The research team programmed various new applications using AR that increases the inspection abilities to quantify the structures (Figure 10).

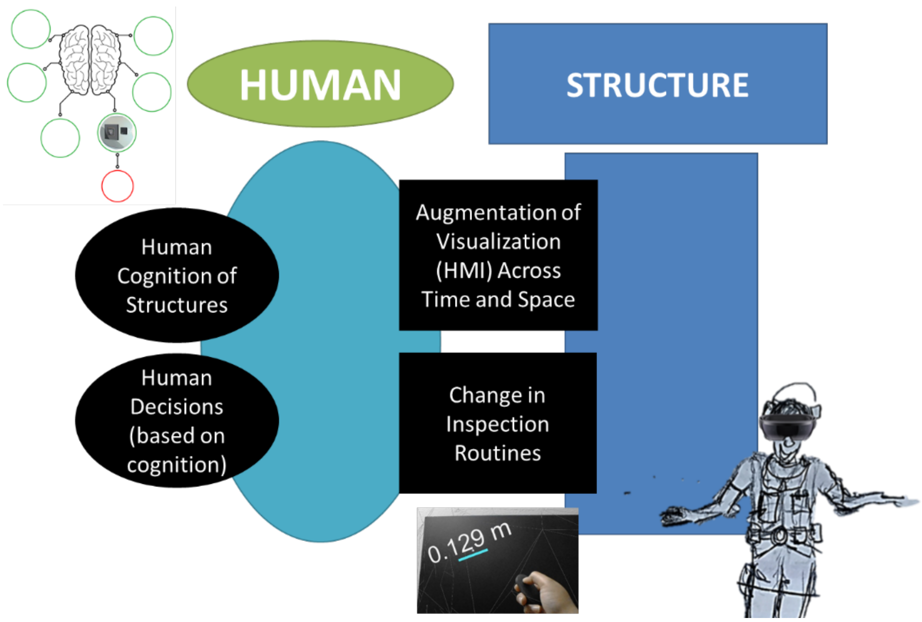


Figure 10. Augmented Inspections using AR.

The programming of AR was processed in Unity, and the assembly and compilation is carried out with Visual Studio. The deployment in HoloLens enables the real-time access to the linked databases, sensors, or other toolsets which can be accessed by the inspector and are also overlaid in the real world through AR. The inspector can now access MSDS files that are linked through the stream socket in front of the cannister with valuable information on PDF format, database of sensors, or can also combine the measurements with a programmed real-time measurement (of cracks, for example). For updates about databases with drawings or past inspections, the inspector can access PDF information which can also be updated in the server, so the inspector can receive the most updated PDF through AR.

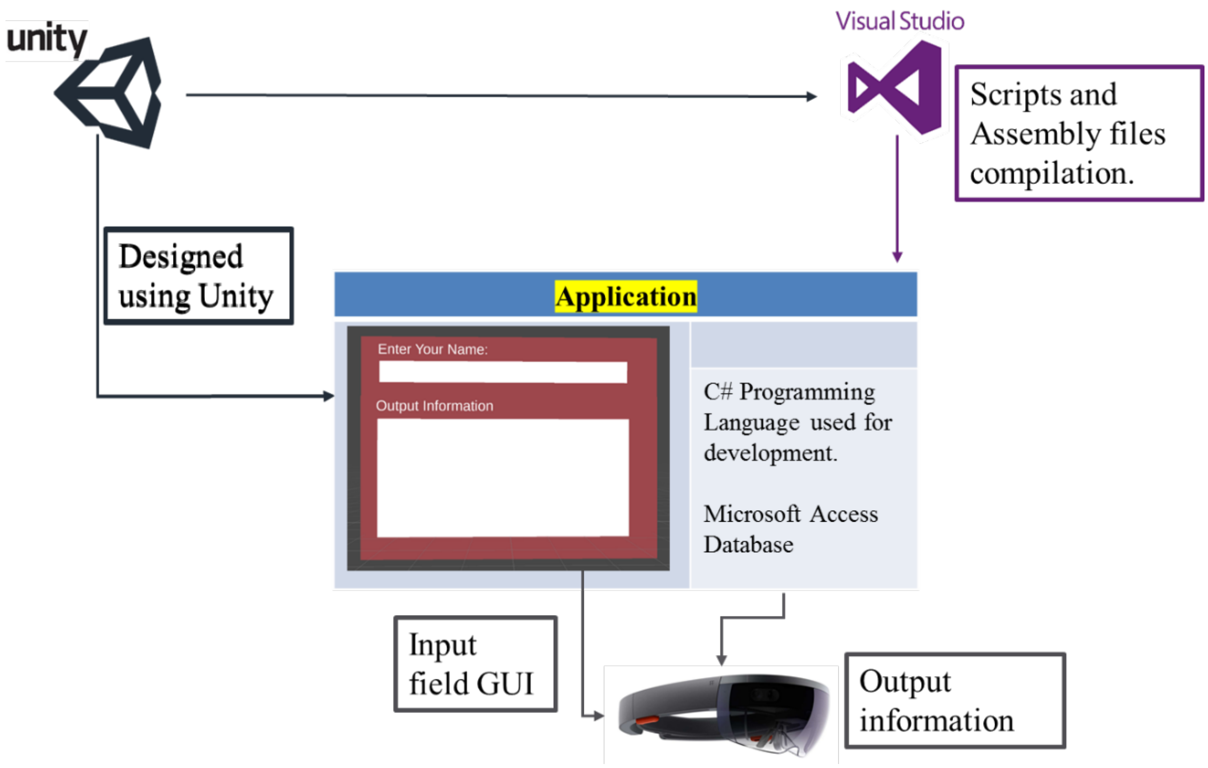


Figure 11. Application development.

4.1.3. Applications Testing Procedures

The research team developed various applications following requests from stakeholders, national laboratories, and emergency agencies such as the city of Albuquerque and Los Alamos County. The research team first asked for AR applications ideas, collecting the needs from industry first. Second, the research team programmed the required software in Unity. The seven applications were: distance measurement, area measurement, barcode measurement, wireless smart sensors and AR, database access, change detector, and spatial dust storm. Third, the team developed hardware. The fourth step consisted laboratory validation with conventional sensors or measurements, for each of the six applications. The comparisons are later on explained for each of the six applications in section 5.2. The fifth step consisted in sharing the application results and accuracy with stakeholders and national laboratories to received feedback. The sixth step consisted in a final demonstration of AR for bridge inspections to the NMDOT bridge inspection to collect feedback.

4.1.4. Augmented Reality Education and Training

The PI, Dr. Moreu, and students who received funding for this project collaborated with LANL to participate in the Los Alamos dynamic summer school (LADSS). This was a continuation of a relationship between the PI and LADSS that began in the summer of 2016 and will continue in the summer of 2019, at no cost to Tran-SET. There are approximately 21 undergraduate students from several academic institutions involved in LADSS annually and the PI will supervise one of their projects related to this research. Knowledge about the research was disseminated to the students, faculty and LANL staff participating in the 2018 summer school and will be also shared in summer 2019. The team organized a series of demonstrations to middle schools and high schools, industry, and NMDOT on AR. In the demonstration to NMDOT, the team received feedback from bridge inspectors on the applicability of AR for their decisions in the bridge management and inspection area.

This majority of this research was conducted at UNM, which is the only Carnegie, Very High Research University in the country designated as a Minority and Hispanic-Serving Institution (MHSI). UNM School of Engineering's (SOE) graduation rates for Hispanic and Native American students are among the highest in the country. Currently, 50 percent of Engineering undergraduates come from underrepresented groups (Native American and Hispanic). The PIs increased the participation of underrepresented students in engineering in this project and additionally provided students with a clear connection between research and industry careers. For example, the PIs actively integrated teaching and research with the development of innovative course materials and by involving undergraduates as research assistants. These PIs attracted underrepresented students to undergraduate and graduate school. The PIs also maintained an active collaboration with community colleges, including the Native American Community Academy (NACA) in Albuquerque, New Mexico and Central New Mexico Community College (CNM).

5. ANALYSIS AND FINDINGS

The results of this research are summarized in four sections, those related to the technical development of new AR applications that are related to the transportation industry, and other outcomes because of education and training. Therefore, the technical analysis and findings achieved with this research can be summarized in the following categories:

- Collaboration with owners of infrastructure: workshop, industry feedback, and opportunities for AR development based on practical implementation in industry.
- Development and validation of AR applications in comparison with current inspection tools and procedures.
- Teaching and training in College level of AR and feedback and interest from students to learn about AR for transportation infrastructure.
- Teaching and training of AR in STEM to increase the interest of youth in science and engineering.

5.1. Collaboration with LAC, City of Albuquerque, Railroads, USDOT, and National Laboratories for use of AR in Transportation Infrastructure Inspections

5.1.1. NMDOT and AR

The result of the various AR progress in the year has contributed to a demonstration of AR to NMDOT on AR and its potential to assist bridge inspectors, which was conducted in NMDOT District 3 headquarters on March 1st. About 15 bridge inspectors attended a practical presentation about the use of AR for bridge inspections. The main component of this activity was the dialog from the NMDOT's perspective of what would be useful as a practical application of AR for their day to day activities. The various results of this interaction are attached.

Figure 12. NMDOT Demonstration on AR (March 1st, 2019).

Figure 13 shows the general background of the bridge inspectors who attended to the demonstrations in the context of their traditional activities at bridges inspectors. Based on their answers, they covered a wide range of areas such as field inspection, maintenance, planning and design, bridge rating and repair, and other (Figure 13).

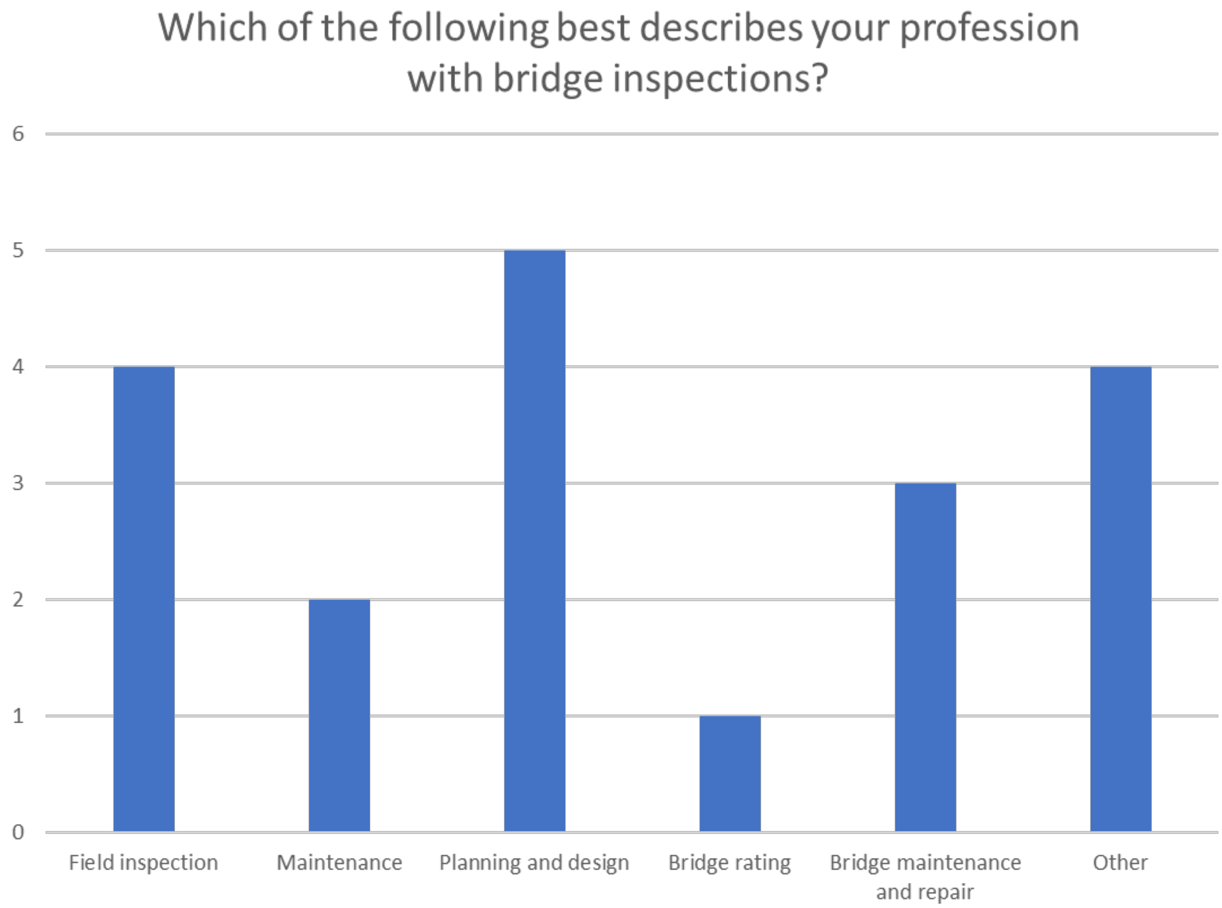


Figure 13. Bridge inspection description.

In order to survey the interest of the profession of bridge inspectors in AR, a series of quantitative questions were asked that requested their level of exposure or interest to various aspects. In this survey, the bridge inspector was asked to fill in their answer to various questions ranging from 1 to 5, with 1 being the least, and 5 being the highest.

Figure 14 summarizes how the current profession of bridge inspector has more than medium interest in AR and new technologies, so they are open and interested to incorporate this technology in their decisions at work.

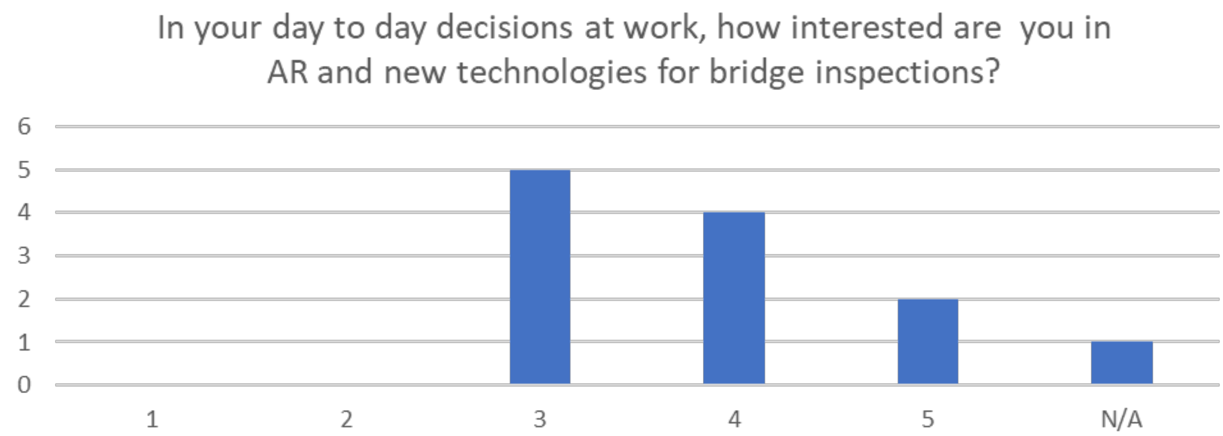


Figure 14. Day-to-day decisions current exposure to AR and new technologies.

Figure 15 shows however that this population has low ratings with their past experiences with technologies for bridge inspection. Based on the discussions in the demonstrations, they would like technologies that are more practical and that they can use during the inspections.

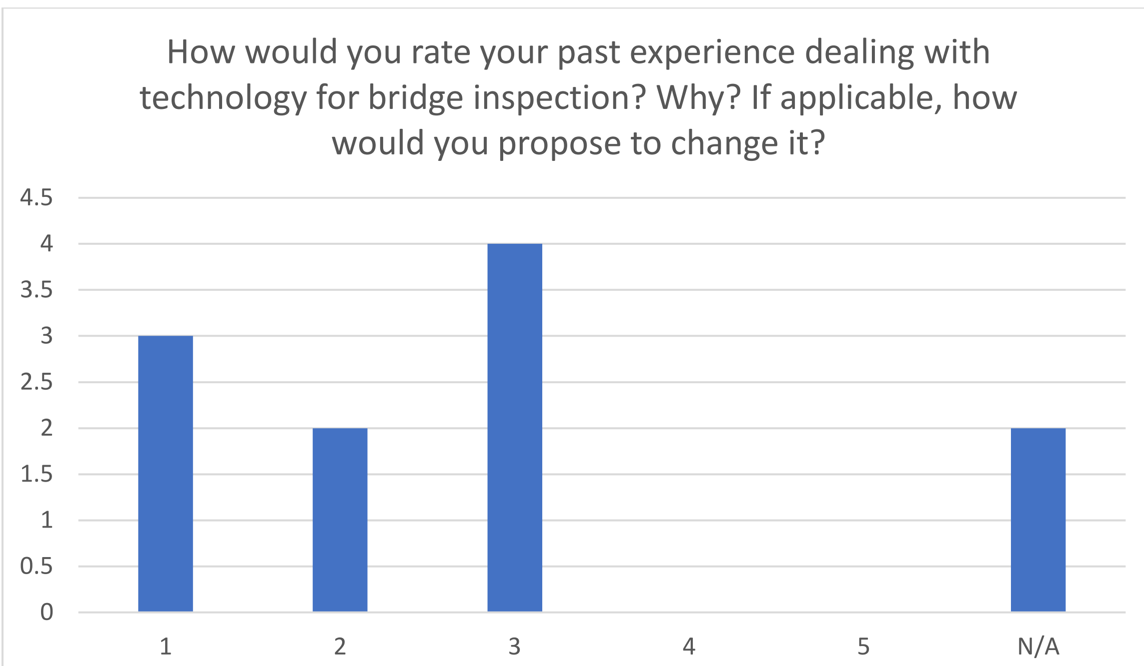


Figure 15. NMDOT demonstration result 1: Technology exposure.

It is interesting observing the results of Figure 16 that the NMDOT bridge inspector population who attended the workshop is interested to learn more about AR for bridge inspections, even they have low ratings on their past experiences with technologies they are in average interested to see how helpful AR can be for their decisions in the field.

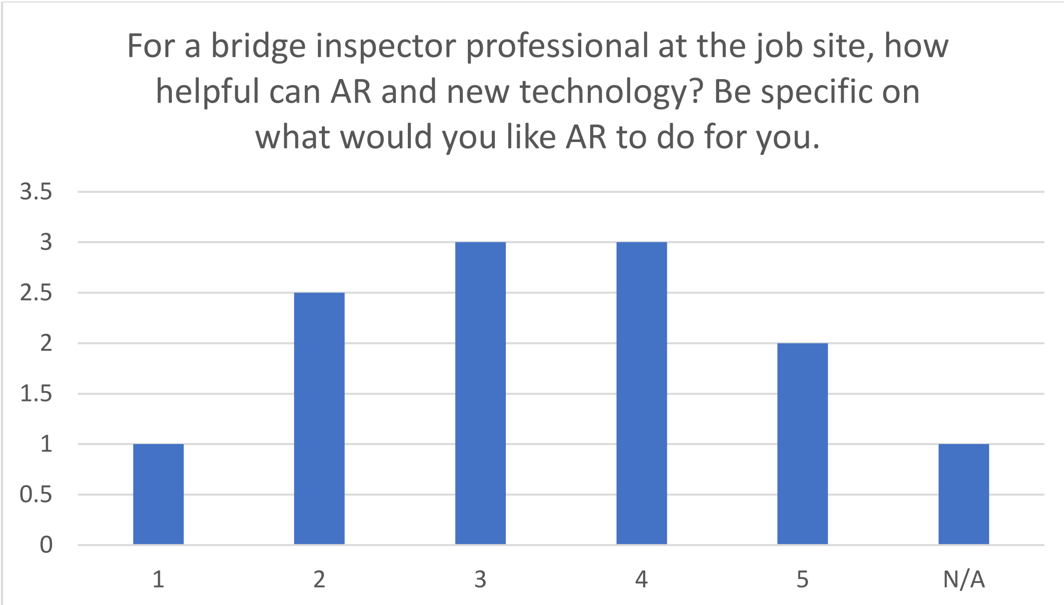


Figure 16. AR potential impact in bridge inspectors.

Figure 17 is a preliminary rating of the value of specific AR applications, in this case AR for crack measurement. In this figure, the values for NMDOT or bridge inspectors are in general high. A reviewed version of this report will include further analysis of their answers for all applications.

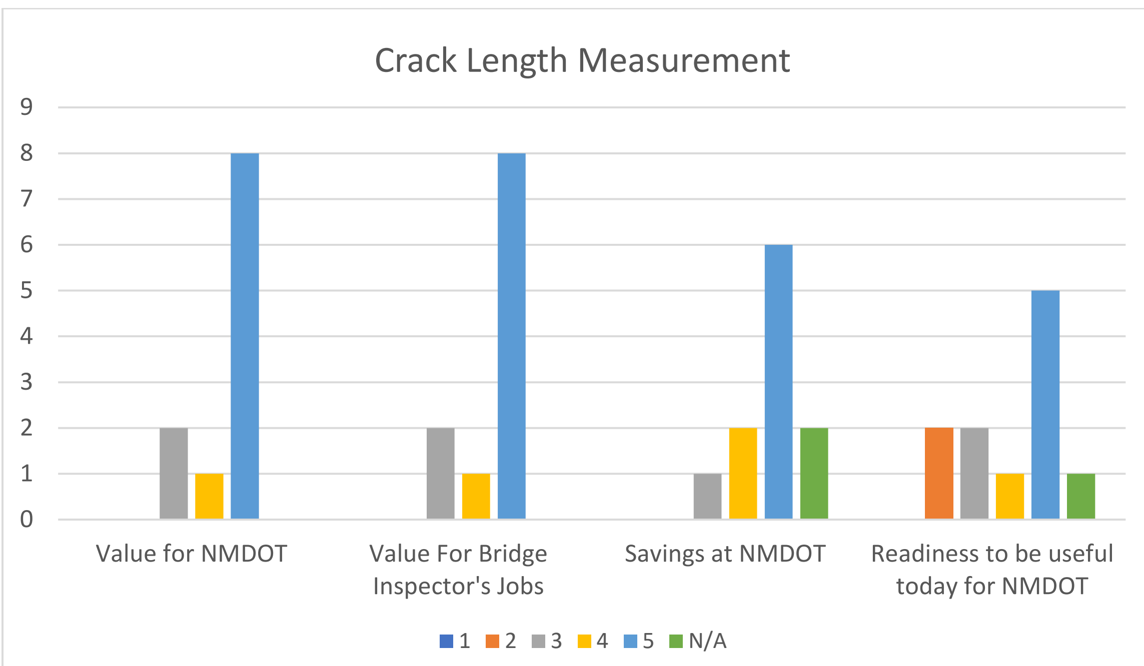


Figure 17. Expected values for AR application on crack measurements.

At the end of the survey, the stakeholders were asked to write ideas for field inspection and AR that they identified of future value. Those ideas included the following:

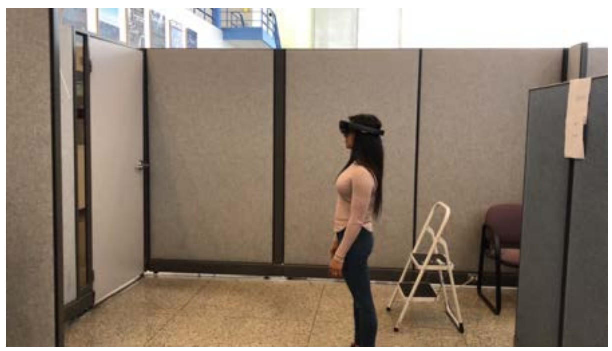
- Crack width measurement under truck crossing events.

- Crack width growth and monitoring across time.
- Server database update from inspectors during inspection.
- Field inspection data anchoring for future inspections.
- Ability to display digital bridge drawings and information in the field during inspections.

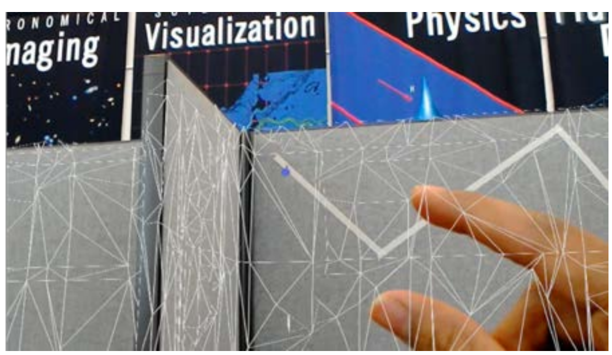
5.2. Collaboration with LANL to Develop Various Applications that can be Benchmarked with LAC, CN, and NMDOT and Benchmark the Accuracy

5.2.1. Distance Measurement

The distance measurement application was developed for bridge inspectors to help achieve improved safety in addition to better work productivity while conducting bridge inspection work. The application allows bridge inspectors to take hands free, non-contact measurement of inaccessible portion of structures. A basic example would be using this application to take linear measurement of length of cracks under the deck slab of a highway bridge. By using this application, a bridge inspector would not have to use the conventional way of measurement such as tape measurements. Figure 18 below shows an undergraduate student using the measurement application to take a measurement at an inaccessible height using basic hand gesture.



(a)



(b)

Figure 18. Crack length measurement using HoloLens. (a) Contact free distance measurement. (b) Hand gesture to record/save the data.

A simple experiment was conducted to test the safety and accuracy of the measurement application. The results show that the application can enhance safety and increase productivity without compromising in accuracy of results. Table 5 shows the comparison between conducting measurements with conventional tape measurer tool and application with AR applications. In order to survey the interest of the profession of bridge inspectors in AR, a series of quantitative questions were asked that requested their level of exposure or interest to various aspects. In this survey, the bridge inspector was asked to fill in their answer to various questions ranging from 1 to 5, with 1 being the least, and 5 being the highest. The results show that the new AR distance measurement is safer, faster, and as accurate (or more) than the traditional measurer tool.

Table 5. Accuracy, safety and productivity comparison between AR application and tape measurer tool.

Decision Criteria	Distance Measurement (AR app)	Tape Measurer Tool (Conventional method)
Required Equipment	HoloLens	Tape Measurer
Safety Risk	Low	Moderate/High
Accuracy	Good	Good
Time expended	12 seconds	33 seconds

5.2.2. Area Measurement

Surface Area Detection and Measurement is an interactive application developed by researchers in collaboration with Los Alamos County. This application helps engineers to take area measurements of concrete surfaces. Using advanced computational spatial mapping technology of Hololens the application is able to sense its surrounding environment and project virtual meshes/triangulations of the area we intend to measure. Figure 19 shows the measurement of area using AR. Figure 20 shows a close up of various areas' measurements conducted for field validation. Table 6 shows the results of the comparison, with the conclusion that the accuracy of AR for area measurement is very satisfactory.

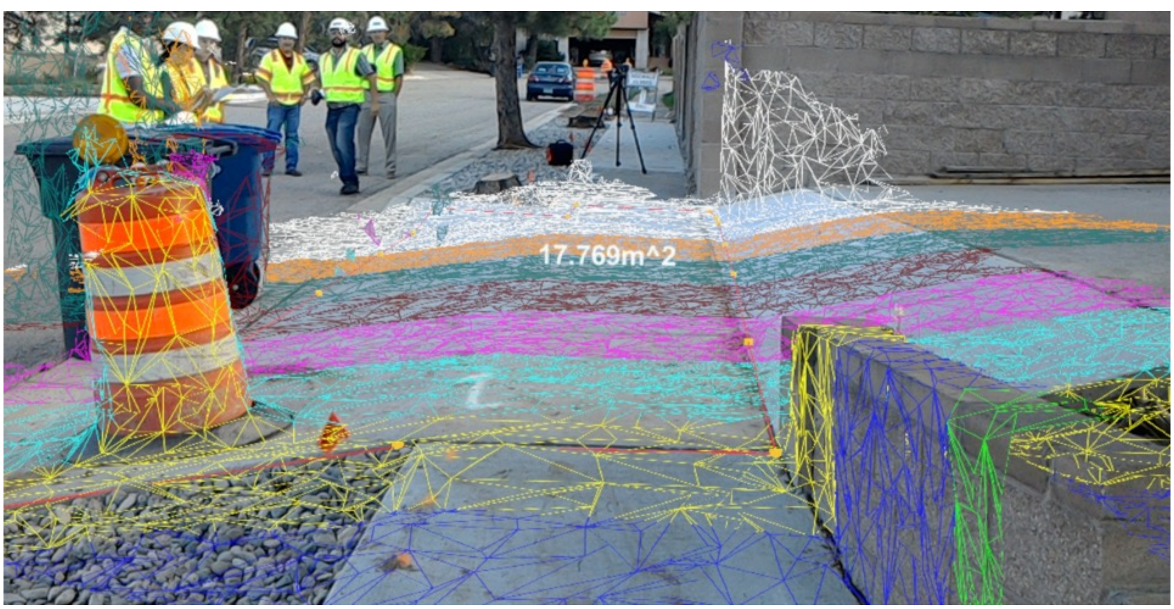


Figure 19. Footpath concrete surface area measurement using HoloLens app.

Figure 20. The surface area measurement app tested three types of concrete surfaces.

Table 6. Comparison of measurements.

Area #	County Measurement (ft^2)	HoloLens Average Measurement (ft^2)	Difference (ft^2)	Difference (%)
Area 1	187.98	191.50	3.52	1.9
Area 2	147.67	149.00	1.33	0.9
Area 3	129.00	127.40	1.60	1.2

5.2.3. Barcode Measurement

Barcode scanning allows to send a search input into a database to send and receive information. Using a laser scanner allows you to quickly access the data in time critical site inspection works. This application includes the development of an Augmented Reality application to integrate the barcode scanner as a USB HID device to be connected to the Microsoft HoloLens. This application allows to read the decoded string of the barcode and program a then program an output to get more visual information of past inspection report. The software has a simple GUI design, containing a 3D rectangle that moves with the head motion, a smaller white 3D rectangle that shows the decoded string of the barcode. This software has been tested with different barcode scanners to see which one provided the most efficiency. Figure 21 shows the human-bar code interface enabled using AR.

Figure 21. AR headset (Microsoft HoloLens) was used to build a system architecture where inspectors could go to site, connect to the remote server and quickly view information by scanning unique barcode.

5.2.4. Wireless Smart Sensors and AR

Wireless Smart Sensors (WSS) are cost-efficient way to record and store data. When connected to AR application, the framework for visualizing and interacting with data becomes much more interactive and intuitive. The cost effectiveness of WSS makes it possible to deploy many sensors in remote locations for longer period. When an inspector visits the site for inspection, he can visualize the data using AR application without having to worry about the data extraction or retrieval. The relevant information is automatically saved to remote server location giving extra layer of cyber security and data privacy. For this research we have successfully integrated two types of WSS: Strain gauge and Accelerometers with the AR headset. The inspector can not only view the past/recorded data but also visualizes near real-time data. Figure 22 shows the architecture of the AR with WSS.

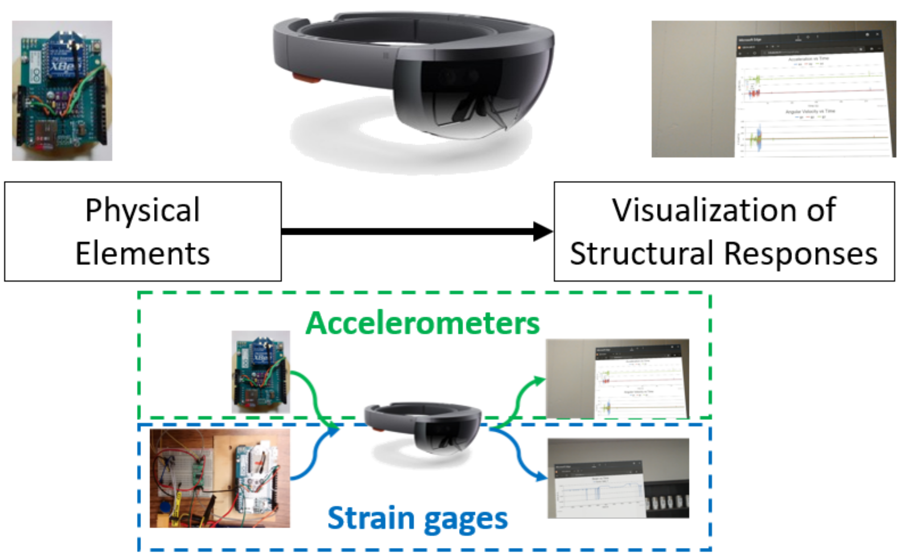


Figure 22. An integration of AR headset with Wireless Smart Sensors to access and visualize near real-time data.

5.2.5. Database Access

The main contribution of this work includes the establishing network connection between the barcode being scanned and a remote database on a distant server. This stream socket connection between the object being scanned and the server allows inspectors to obtain real-time information from the server, and store information of the inspection in the server. The final objective of this work is to augment the human perception of their environment to be faster and more accurate with the use of augmented reality and barcodes in the context of bridge inspection. Having quick access to past inspection reports is not only critical for bridge inspector to optimize their workflow but also and important aspect for owners to make their decision on bridge inspection works. Figure 23 show the inspector – data base connection through server using AR.

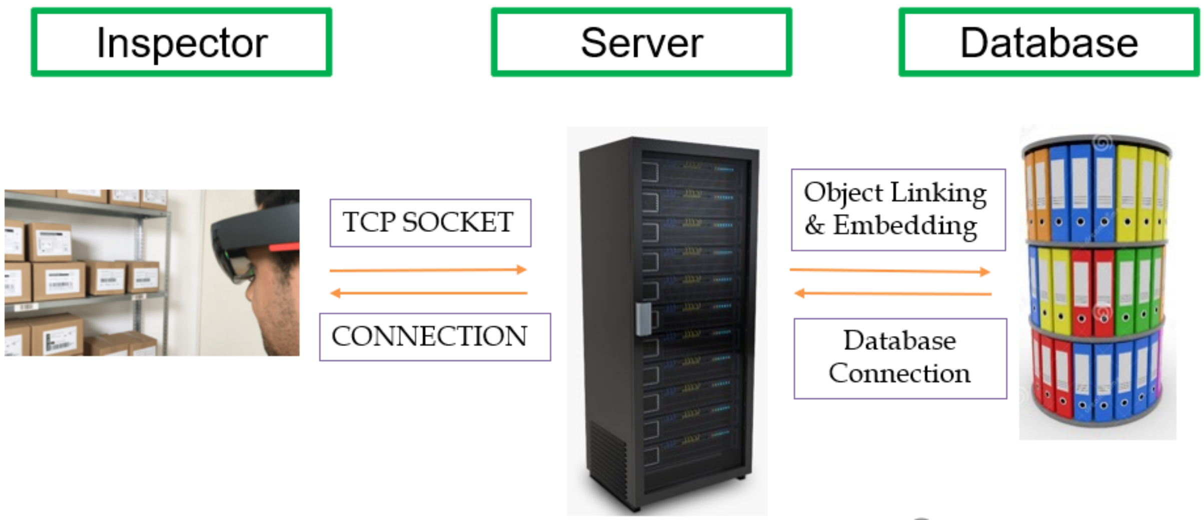
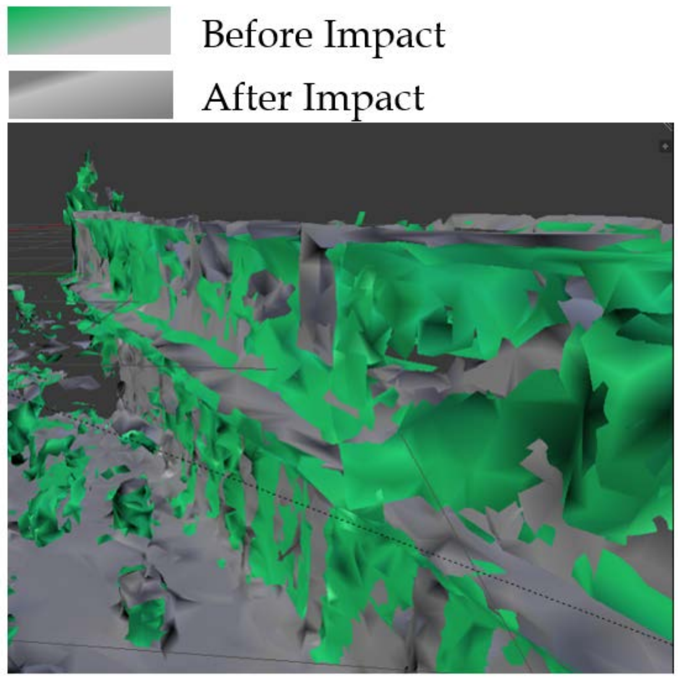


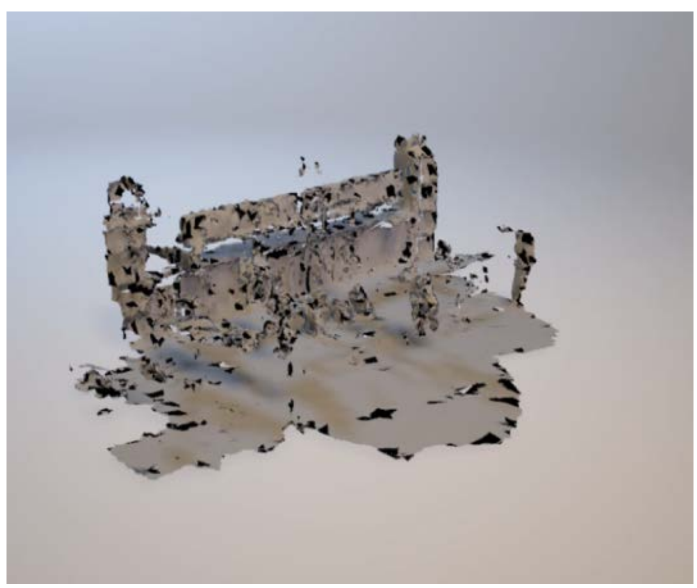
Figure 23. Database using AR.

5.2.6. Change Detector

The change detector is an innovative way to look around the dynamic changes happening in your real-world environment. The application allows the user to go back on time and see if there have been any changes in the surrounding. An interactive and visually intuitive way is provided which allows the user to overlay past renderings on top of new ones. In context of bridge inspection task, which may take several visits to the site, this application can render past inspection information on top of new information and see the modification on site. A basic example would be measurement of crack and crack length propagation through time history. With every inspection carried out on that site, even a new inspection crew member is able to understand the inspection history and redrive information without having to go through all the past documentation. Figure 24 shows the comparison before and after impact of the bridge for change detection.



(a)



(b)

Figure 24. The Change Detector Application is used to compare an experimental beam specimen before and after the impact. (a) Overlay of new rendering (shown in green) on top of old rendering (shown in grey). (b) A rendering of overall shape of the beam specimen.

5.2.7. Spatial Dust Storm

Spatial Dust Storm is an interactive AR application that allows the user to create virtual dust storm around his surroundings. The dynamic dust storm environment is useful to simulate real world like environment in a virtual setting. The value it brings to transportation engineering community is that it allows to train amateurs inspectors for adverse environments during the field inspections. Hazardous environments like high gusty wind, heavy rain or snow can affect the quality of inspection. To see the effect of these environmental condition is important to be able to simulate in various conditions. We would like to quantify this without having to go out in the field and expose ourselves in those environments. With this application it is possible to achieve that in a closed environment. The future version of application can take the user analytics and see how different user is able to navigate under different environment conditions. Ultimately, the goal is to create uniformity in inspection work carried out by different inspection at different environment conditions. Figure 25 shows the spatial dust storm application with intensity menu.

Figure 25. Spatial Dust Storm application understands your real surrounding environment and creates the simulated dust storm around it.

5.3. Involve Both Students and Industry for Augmented Reality Education and Training

The following sections list the various results and from the education and training using AR that are a result of the one-year implementation of training youth and professional on AR.

5.3.1. Augmented Reality for UG (Fall 2018)

In the Fall of 2018, the concept of AR was introduced in the Civil Engineering course of Steel Design (CE424/524) as a tool to increase the real time assessment of structures during construction, or under loads. By using strain gages that were created and designed for this application on AR, the result was that the average senior student in civil engineering appreciated AR as a tool for steel design and inspection. As a consequence, in the final group competition, the winning group was that presenting AR for steel structural inspections, as judged by the students in the class of steel design (Figure 26).

Figure 26. Undergraduate introduction to AR.

5.3.2. Augmented Reality for UG RA (Spring 2019)

As a result of the successful experience in the fall of 2018, two undergraduate students were added to the research in AR, as they both became interested in using AR for research in civil engineering and structural engineering. As a consequence, they have assisted in advancing the use of AR for comparison of conventional and new AR assisted inspections, a new application in AR where the inspector overlays confusion in their environment to train against adverse conditions, and also developed the wireless hotspot to use AR outdoors. Figure 27 shows a graduate student programming AR for UG assistants to test bridge inspection applications in the laboratory.

Figure 27. Graduate student developing AR for UG assistant tasks.

5.3.3. Augmented Reality for FRA (Fall 2018 and Spring 2019)

In both fall 2018 and spring 2019, the results of AR have been shared with FRA to discuss possible applications were railroad inspectors can increase safety during maintenance of critical rail infrastructure. In March 25-27, the PI and the AR students are attending the 24th Annual Research Review in Colorado to discuss further with the railroads the implementation of AR for inspection and maintenance of critical railroad infrastructure. The results have been that the FRA is becoming more interested in AR if it can increase the safety of railroad employees during inspections,

5.3.4. Augmented Reality for NCHRP (Fall 2018)

The research team developed a suite of tools for AR that were shared with a national webinar hosted by TRB and NCHRP which was recorded on December 2018 (Figure 28) and has been downloaded over 300 times. This webinar has reflected the high interest in NCHRP in AR for transportation industry, but also generated interest in NMDOT which are now considering AR as a possible tool for bridge inspectors so they can conduct inspections which are more accurate, faster and safer using AR.

Figure 28. NCHRP webinar (over 307 viewers since December 7, 2018.)

5.3.5. Augmented Reality for NASA (Fall 2018)

The research team visited the International Symposium for Commercial and Personal Spaceflight (ISCPS) and discuss various interactions between AR for transportation infrastructure inspection to space explorations and assessment of built infrastructure in Mars (Figure 29). The result is that

AR can be an effective technology beyond infrastructure inspection and can receive support from other agencies to advance transportation maintenance.

Figure 29. NASA conference to discuss AR.

5.3.6. AR for Super STEM

The outreach activities included presented to children from New Mexico at the 2019 Super STEM event where graduate students introduced AR as a technology for increase assessment and cognition (Figure 30). Parents and children attended the SMILab booth to learn more about new and emerging engineering technologies that increase the perception of humans about their surrounding environment.

Figure 30. AR for the youth engagement in STEM.

5.3.7. AR for NMC (Spring 2019 class)

As a result of this collaboration with the Air Force and the AR research developed with TranSET, a new collaboration between NMC and UNM has been established where NMC students are developing new software skills that will enable to consider transportation as an application of their software programming skills in AR. The result is that one of their courses is dedicated to program in AR that can be eventually used for inspections of infrastructure. The NMC students interacted with the UNM students as part of their class (Figure 31).

Figure 31. AR collaboration with CNM and UNM: CNM students learn AR from UNM.

5.3.8. AR and MATLAB

The research team has developed a sensor network using MATLAB that allows the connection of AR with the data processing tool. The research team showed the integration of AR with MATLAB to the founder of MATLAB Cleve Moler during one visit to UNM's SOE (Figure 32).

Figure 32. Discussion with MATLAB Founder on new technologies for augmented inspection using Arduino and AR.

5.3.9. AR Presented at International Venues

The results of this one-year project has been shared in multiple venues and conferences. The outstanding international venues include a special session in the 9th International Conference on Structural Health Monitoring of Intelligent Infrastructure in Saint Louis, MO, in August 2019 and another special session in the 12th International Workshops in Structural Health Monitoring (IWSHM) in Stanford, CA.

5.4. Teach the First Class on AR for Transportation Infrastructure Inspections in UNM for High School Students at the STI

5.4.1. Augmented Reality for High Schools, Undergraduates (Summer 2018)

Since summer 2018 this research team has introduced high school students and undergraduate students to the use of AR for intelligent assessment and inspection of transportation infrastructure (Figure 33). The results are that younger generations are interested in pursuing technical activities that enable them to relate technical development to transformation of activities related to transportation infrastructure management.

Figure 33. Highschool outreach using AR.

5.5. Workshop with Universities, National Laboratories, Stakeholders, to Summarize the Achievements

5.5.1. Augmented Reality for AFRL (Spring 2019)

The AR team is adapting the ability of AR to measure and quantify changes in structures in real time to attract other sources of support to research such as the Air Force. The research on AR was presented at the February 28th Showcase of the AFRL in STC New Mexico, which attracted various companies interested to invest in AR (Figure 34).

Figure 34. AR for augmented assessment of the environment, AFRL showcase.

6. CONCLUSIONS

This research project has identified the following conclusions based on the development, technical validation, surveys, and presentations in the year-long project:

1. AR can be programmed for practical decision-making applications that increase the accuracy of the quantification of 1D and 2D measurements with less than 2% error.
2. Owners find AR of value for their inspections, including counties, and are interested in further validation of the practical implementation of AR in the field.
3. AR can increase accuracy of inspections while also save time of the inspection, when benchmarked against conventional inspections.
4. AR can assist inspectors to access databases across time and space, so inspectors can access in the field databases that can be shared during the inspection.
5. The hands free and ability of inspectors of overlaying objective information during the inspection has been identified to be of value for owners.
6. AR has been demonstrated to be useful to transform the assessment of changes in the field in real time by inspectors, as well as to compare across time changes in volume, which was not possible before.
7. Field, state, and local state-wide bridge inspectors are willing to provide more input to make AR valuable for their inspections.
8. Students of all ages are interested in programming and developing AR as a tool to increase their interaction with their environment.
9. Numerous students have been attracted to research in structural inspections and transportation infrastructure, and have joined the research group to develop AR. Many are now considering now moving on to school.
10. Youth shows interest in inspecting bridges due to their interest in AR.

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APPENDIX A: NMDOT SURVEY (MARCH 1st)

A.1. Pre-Presentation Survey

Bridge Inspections Using Augmented Reality and Other New Technologies

Pre-Presentation Survey

1. Which of the following best describes your profession associated with bridge inspections?

   ☐ Field Inspection ☐ Maintenance ☐ Planning and Design ☐ Bridge Rating ☐ Bridge Maintenance and Repair ☐ Other (which one?)

2. In your day to day decisions at work, how interested are you in AR and new technologies for bridge inspections?

   (Lowest 1 to Highest 5)

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3. How would you rate your past experiences dealing with technology for bridge inspection? Why? If applicable, how would you propose to change it?

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

4. For a bridge inspector professional at the job site, how helpful can AR and new technology? Be specific on what would you like AR to do for you

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

5. What are the current needs that are unmet by available technologies that you would like to see developed further by researchers based on your needs during bridge inspections?

A.2. Post-Presentation Survey

Bridge Inspections Using Augmented Reality and Other New Technologies

Post-Presentation Survey

1. Which of the following best describes your profession associated with bridge inspections?

☐ Field Inspection ☐ Maintenance ☐ Planning and Design ☐ Bridge Rating ☐ Bridge Maintenance and Repair ☐ Other (which one?)

2. How helpful/useful did you find this presentation in understanding AR as a new technology for bridge inspections? Did it meet your expectations? (Lowest 1 to Highest 5)

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3. Will you be interested in attending another AR presentation for you like this one? (Lowest 1 to Highest 5)

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

4. How comfortable are you considering AR technologies in your future work for bridge inspections?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

5. How optimistic are you with current research being conducted in the field of AR for bridge monitoring?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

6. How optimistic are you in bridge inspector using Augmented Reality (AR) technology for work in future?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

7. In your opinion, what kind of technologies related to infrastructure management would be beneficial for Bridge Inspector? List all that you would like to have.

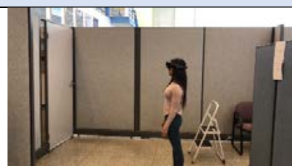
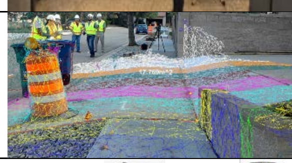
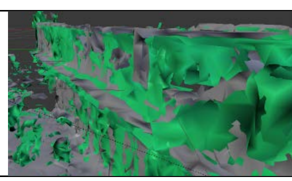
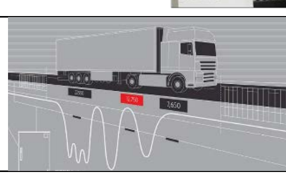
A.3. Post-Presentation Survey (Ranking)

Smart Management *of* Infrastructure Laboratory

SCHOOL OF ENGINEERING

Bridge Inspections Using Augmented Reality

Score each of the following AR ideas in the four listed categories from 1 (low) to 5 (high)

	Photograph	**Value for NMDOT (1 to 5)**	**Value for Bridge Inspectors' Jobs (1 to 5)**	**Savings at NMDOT (1 to 5)**	**Readiness to be useful today for NMDOT (1 to 5)**
Crack Length Measurement					
Area Measurement					
Bridge Inspection Management (Bar Code Scanner)					
Change Detector					
Real-Time Strain Data					
Bridge Weigh-in-Motion (BWIM)					
Your IDEA!					

A.4. Post-Presentation Survey (Feedback)

Bridge Inspections Using Augmented Reality and Other New Technologies

Feedback

1. What kind of topics relating to bridge inspection would you like to know more about in future workshops and seminars?

2. What areas can Augmented Reality (AR) can improve in the work you do currently for bridge inspection?

3. In 5 to 10 years what technological advancement would you like to see in highway bridge monitoring (be as creative as possible, you can ask for anything you are missing today that you think should be done for research)?

4. How do you see new technology could improve your job in day to day work?

5. How do you see new technology could improve your profession in general in day to day work?

6. What suggestions do you have for workshop organizers?

APPENDIX B: NMC COURSES IN AUGMENTED REALITY (EXAMPLE)

CIS 2250 Game and Simulation Development

Augmented Reality Deforming Model Simulation

Objectives:

- Demonstrate how to create an Augmented Reality application
- Demonstrate how to use Agile Software Development to organize a project
- Demonstrate how to create asset packages in Unity3D
- Demonstrate how to document a code base using html doc comments
- Demonstrate how to use stylecop to ensure delivered code is well formatted
- Demonstrate how to use the Mesh class in Unity3D to modify a 3D object

Turn in requirements:

1. Please name your Program LastnameP7, such as NelsonP7.
2. Please staple a printout of your Form1.cs file to this page to hand in.
3. Check program into source control.

Program Requirements:

Given a formula that represents an object's deformation, create an AR representation object deforming under a side-to-side load. Superimpose the representation on an actual experiment to see if it matches the movement accurately. Figure out what would be best approach to locate the model in the scene. Use an image target or let user set initial position manually and just reference the floor.

You will be delivering this code to a team of graduate students. They may or may not use your solution depending on how suitable it is.

Code must be very well documented. Use Style cop and XML documentation comments to make a well documented code base.

You must deliver a unity project that demonstrates how to use your framework.

You must include unity prefabs and a unity package that can be used to import the capability into another unity project.

Testing:

Print out a paper target and manually move it back and forth to see if it follows the target. If you find the system can't follow the target fast enough consider designing the code so that the motion platform itself is also simulated. Ask me for clarification if this doesn't make sense.

For a test with the actual system let me know when you are ready and I will make arrangements with UNM.

Hints:

See https://library.vuforia.com/articles/Training/getting-started-with-vuforia-in-unity.html for documentation on using Vuforia for augmented reality applications.

See https://docs.unity3d.com/Manual/GeneratingMeshGeometryProcedurally.html for information on how to programmatically edit mesh geometry.

See https://github.com/StyleCop/StyleCop for information on how top install style cop. You can install stylecop from the package manager console in Visual Studio 2017.

See https://docs.microsoft.com/en-us/dotnet/csharp/programming-guide/xmldoc/xml-documentation-comments and https://docs.microsoft.com/en-us/dotnet/csharp/codedoc for information on XML documentation comments.

See https://docs.unity3d.com/Manual/Prefabs.html for information on prefabs.

See https://docs.unity3d.com/Manual/AssetPackages.html for information on how to create and import packages. Make sure you test the packages you create! Create an empty unity application and import your package to make sure it works. You will need to figure out what you need to put in the package to make it useful.