Integrated Hazard Vulnerability Assessment and Mitigation Framework with Mixed Reality for Transportation Infrastructures

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Project Objective

The goal of this research is to develop and test an immersive and interactive mixed reality (MR) framework for hazard risk assessment and maintenance of mega structure systems such as bridges or arches on the location of the project. The proposed framework utilizes the HoloLens to visualize the interested structure, interact with the surrounding in a real time manner, and to virtually show the effect of any observed damage on the hazard resilience. To achieve this goal, the authors set the objectives of (1) developing a virtual prototype of a target structured system; (2) programming the different interactive actions with elements of the studied model; (3) developing different fragility curves for the proposed prototype; (4) visualizing vulnerability analysis results with its virtual model to show how a certain damage can affects the overall structural performance; and (5) testing the interactive experience. The authors believe that this research will be the first step to develop a more advanced virtual structural representation, present risk assessment results against natural hazards, and develop totally interactive MR framework where the fragility curves will be updated in a real-time manner to reflect the aging effect on the structure and its tolerance to loads over time.

Problem Statement

The USDOT's primary objectives are to maintain stability of transportation infrastructures and increase their resilience. Every year, millions of dollars in maintenance costs are incurred due to the performance degradation affected by physical or chemical damages of transportation infrastructures (such as roads and bridges). The damaged pieces of civil infrastructures become more susceptible to natural disasters including earthquakes, tsunamis, floods, storms, and rising sea levels. The damage data from routine structural safety inspections do not immediately indicate how significant or crucial the observed damage would be to the entire system's ability to withstand natural disasters. For the best transportation management and risk reduction strategy, it is more important to know what kind of structural performance degradation the damage will cause. A simulation-based technique called Monte Carlo Simulation (MCS) is widely used to determine hazard vulnerability or fragility curves, which show how well a given structure would perform under an assumed hazard event. However, the MCS approach is often unsuitable due to convergence and computational cost issues. As a result, a novel vulnerability assessment technique is required to handle computationally expensive structural models regularly updated with damage data and to estimate structural failure likelihood rapidly. Towards this end, a platform for integrated hazard risk assessment is required to conduct serious of vulnerability simulations, identify critical damages that have the potential to adversely affect the structure's overall performance, and estimate the resilience reduction caused by such critical damages. However, it would still be challenging for non-engineers to understand final results from advanced vulnerability analysis. Decision-makers will benefit immensely from using mixed reality techniques in presenting the assessment results.

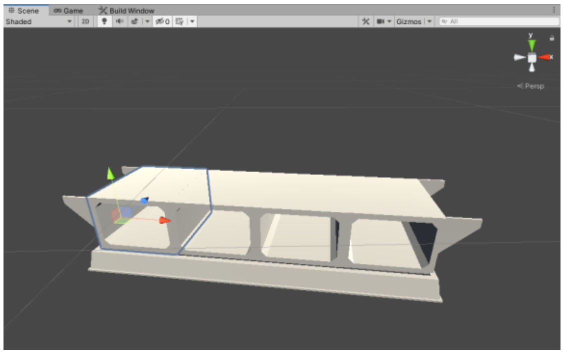
Research Methodology

This research utilizes and integrates concepts from structure fragility analysis, simulation modeling, and interactive programming into one advanced monitoring framework. First, structural performance of a target 4-span concrete bridge was assessed with selected earthquake events. A detailed numerical model was adopted to represent realistic seismic behavior and its hazard resilience was evaluated under the computationally efficient fragility analysis framework. The hazard vulnerability information was presented by the fragility curve. Then, a 3D modeling of the studied bridge was modeled on Unity software; this platform can be used to create an exact replica of a megastructure project, including all the required levels of details. Different interactive actions with the 3D model were programmed to suit the Microsoft HoloLens requirements, such as hovering over objects, clicking, presenting the fragility plots, and making different sounds. The interactive model was installed on the first generation of HoloLens and tested with a small sample of individuals. The model simulates a structure prototype, animates the different parts, allows the user to interact with them, and presents the updated fragility curves with changes over time. One of the main contributions of this work is to save time and effort to present accurate health status and fragility of the target structure over time. The interactive model can be used on-site, where the HoloLens may be used to get the computational data instantaneously.

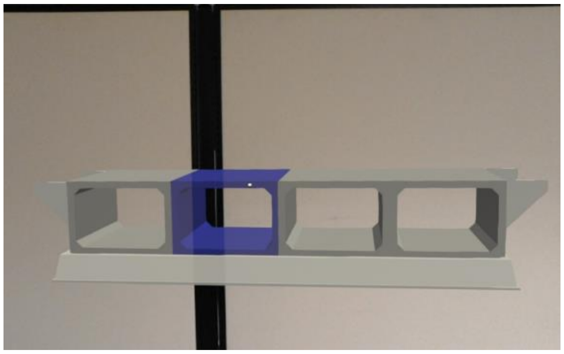
Results

The following are the primary findings from this project. A mixed reality-based hazard vulnerability assessment and mitigation system for transportation infrastructure was created, allowing users to explore any available date interactively with 3D visualization. Though the developed system how the damaged structural system will function against the selected natural hazard event is virtually presented; it would help city planners assess the transportation system's hazard exposure and create investment plans for infrastructure upkeep that would increase resilience. This research will benefit the engineers and practitioners working on the next generation of infrastructure management systems.

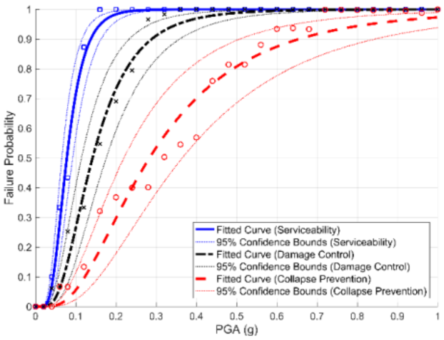
Prototype MR Bridge Model



Prototype MR Bridge Model from HoloLens



Derived Fragility Curves



Fragility Curve with the Prototype MR Model