Human-centered Steel Bridge Inspection enabled by Augmented Reality and Artificial Intelligence

1. Executive Summary:

State DOTs currently are relying on trained inspectors to visually inspect bridge components for detecting structural deterioration and damage, which can be limited in accuracy, speed, repeatability, and reliability. On the other hand, computer vision (CV) can see what human eyes cannot, and artificial intelligence (AI) such as deep learning has shown tremendous ability to conceptualize and generalize. By integrating CV and Augmented Reality (AR), a recent NCHRP Highway IDEA project (Li et al., 2022) completed by this project team successfully demonstrated how human-centered AR environment and automated CV algorithms can empower bridge inspectors to perform more accurate and efficient field inspections of steel bridges for fatigue cracks. The pilot study also identified gaps and further development needs towards adoption of this tool in practical bridge inspections. The goal of this proposed pooled fund study is to develop a full-fledged AR-based bridge inspection tool that leverages CV and AI to support field detection, quantification, and documentation of various damages and deteriorations for steel bridges.

2. Background and Objectives:

Fatigue cracks developed under repetitive traffic loads are a major threat to the structural integrity of steel bridges. In addition, corrosion is another major factor that affects steel bridge integrity as corrosion reduces member strength and can also accelerate fatigue cracking. Human visual inspection is currently the de facto approach for crack and corrosion detection. However, due to human limitations and the complex nature of bridge structures, steel bridge inspections are time consuming, labor intensive, and lack reliability. Although non-destructive testing (NDT) techniques such as ultrasonic testing and acoustic emission have been used as supplemental methods to human visual inspection, they require complex testing equipment, and thus are not broadly used. As a result, inspecting the large steel bridge inventory in the United States remains a great challenge due to the lack of a human-centered, efficient and cost-effective methodology for detecting, tracking, and documenting fatigue cracks and corrosion. On the other hand, if crack and corrosion inspections could inform the inspector in the field, more reliable, efficient, and accurate assessment of the inventory could be achieved and documented.

Recently, computer vision has shown great potential as a non-contact, low-cost, and versatile platform for structural health monitoring. However, distinguishing real fatigue cracks from crack-like surface features, such as scratches, corrosion marks, and structural boundaries remains a major challenge (Kong and Li, 2018). In addition, inspectors currently lack an effective way to efficiently interact with new and historic inspection data. Such human-centered ability has been identified as one of the top interests of bridge inspectors, as it not only improves inspection quality but also facilitates decision-making in the field. To overcome these challenges, through an NCHRP Highway IDEA project (Li et al., 2022), the team recently proposed an entirely new concept and developed a human-centered fatigue crack inspection tool by integrating AR and CV. As illustrated in Figure 1, the inspector wearing an AR headset (Microsoft HoloLens 2) examines the steel bridge and records a short video of the target structural surface through the headset. The video is then automatically uploaded to the server, where the computer vision algorithm analyzes the video by detecting and analyzing surface motion through feature points (pinks dots in the upper right figure). These feature points are then projected in near real time in front of the inspector's eyes as holograms through the AR headset, allowing the inspector to interact with the hologram through a virtual menu to examine the results under different threshold values for crack detection, enabling human-in-the-loop decision-making.

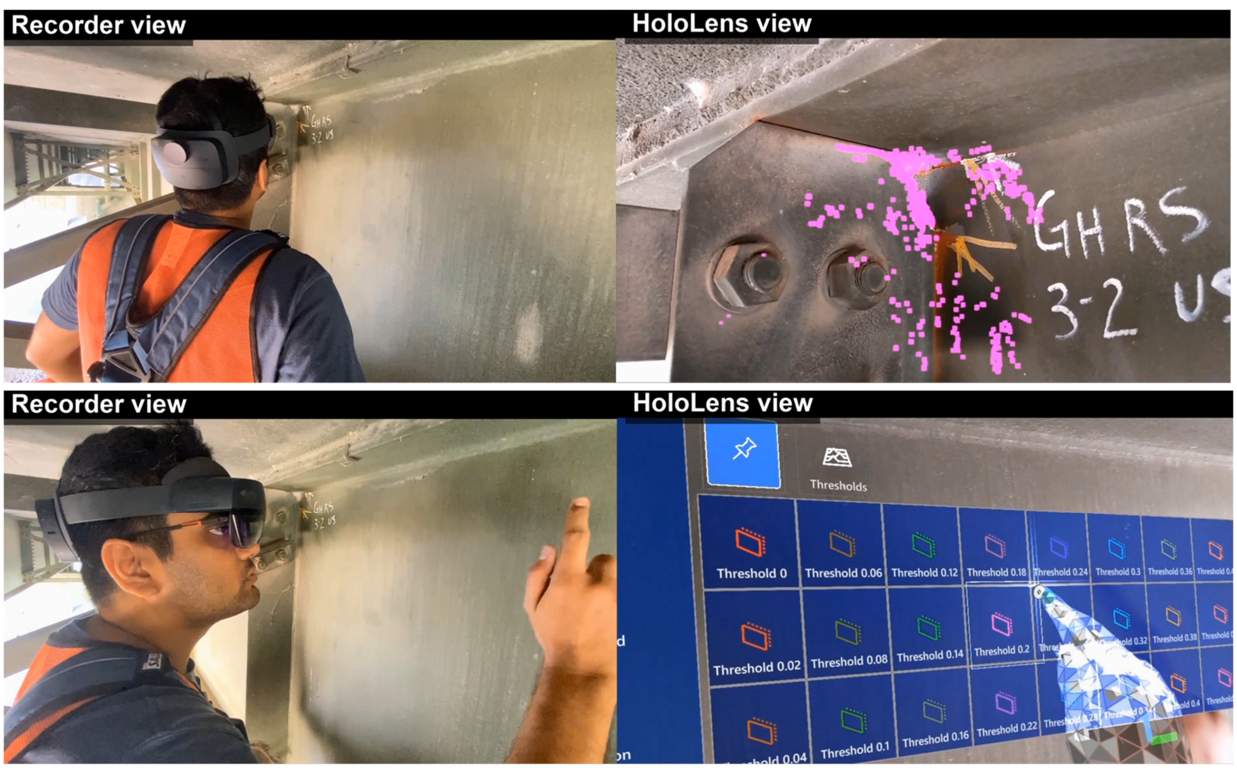

Figure 1. Human-centered fatigue crack inspection tool developed under NCHRP IDEA 223

The NCHRP Highway IDEA project has successfully demonstrated the concept of human-centered bridge inspection by integrating CV and AR using an AR headset as the hardware platform. However, further developments are needed for successful adoption of this tool in practical bridge inspections. In addition, the idea of human-centered bridge inspection would have a broader impact if realized on a wider range of mobile platforms such as tablet devices. The main objective of this proposed research is to provide state DOTs practical tools for supporting human-centered steel bridge inspection with real-time defect (e.g., fatigue cracks and corrosion) detection, documentation, tracking, and decision making. The proposed research will not only bridge the gaps identified in the IDEA project, but also expand the existing capability by developing AI algorithms for crack and corrosion detection. In addition to AR headsets, the project will also develop AR-based inspection capability using tablet devices. The tablet device can be used to perform AR-based inspection directly in a similar way to the AR headset. It can also leverage Unmanned Aerial Vehicles (UAV) for remote image and video acquisition during inspections, enabling bridge inspections from a distance in a human-centered manner, as illustrated in Figure 2.

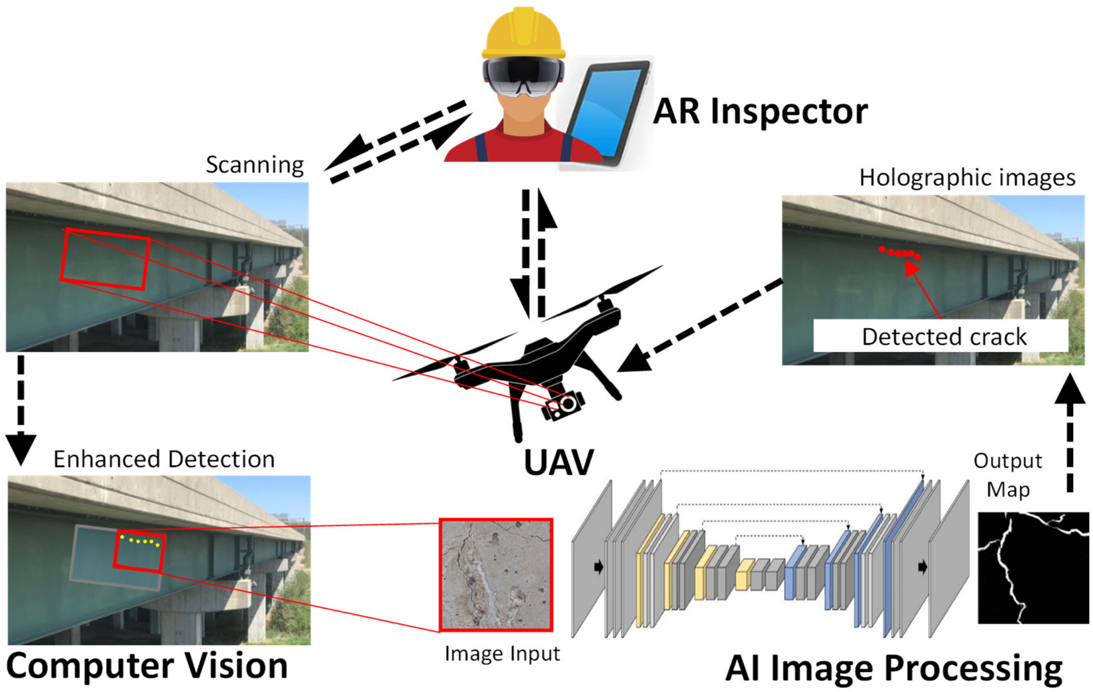

Figure 2. Human-centered bridge inspection enabled by integrating AI, AR, and UAV

3. Scope of Work:

The scope of work includes three main tasks from the development and creation of CV and AI algorithms for steel fatigue crack and corrosion detection and quantification (Task 1), comprehensive design and development of AR-based software to facilitate human-centered damage detection, visualization, documentation, tracking, and decision-making (Task 2), and extensive laboratory and field implementation, testing, and evaluation (Task 3).

Task 1: CV and AI algorithms for crack and corrosion inspection

Two types of algorithms will be included in the AR inspection tool. The first method is based on video analysis and will be improved upon the NCHRP IDEA product in terms of accuracy and sensitivity. In addition, this research will also include image-based deep learning algorithms to enable classification, detection, and segmentation of cracks and corrosion, as illustrated in Figure 3 for the case of crack identification, using images taken by the AR headset, tablet, or UAV. Focus will be placed on minimizing the complexity of the deep learning model to reduce computation, with the goal of enabling real-time image processing and damage inference for practical inspections. With the two methods available, the inspector can first use the image-based deep learning method to identify and segment the regions where cracks and corrosion may exist, then apply the video-based algorithm to further examine the crack region for a refined result.

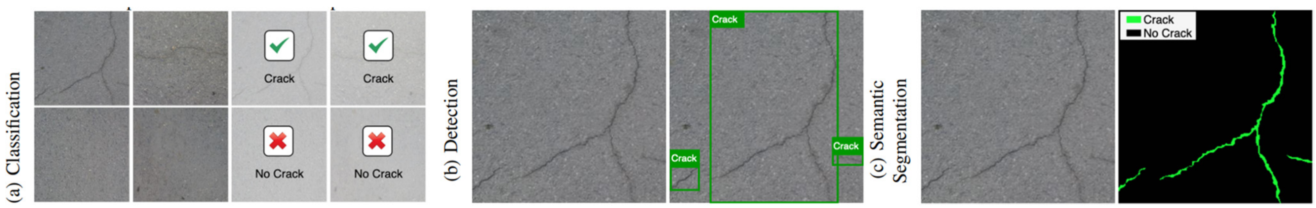

Figure 3. Classification, detection, and segmentation of cracks using deep learning

Task 2: AR-based software for human-center bridge inspection

This task will develop AR-based software environment and user interface to enable human-in-the-loop decision making during field inspections. A process will be developed to convert the damage detection result into holograms and deploy them to the 3D real-world environment with accurate anchorage onto the structural surface. A cloud database will be created to store inspection results. This ability is the key to enabling documentation, allowing for comparisons and tracking of bridge damage in space and time. Build upon the user interface developed in the NCHRP Highway IDEA project, a more comprehensive virtual menu will be created to facilitate a smooth and user-friendly interface for human-centered bridge inspection. In addition, the software for AR headset will be adapted to enable AR-based inspection by using a tablet device. When a UAV is used to facilitate bridge inspection from a distance, the tablet device will receive the damage detection result for the inspector to facilitate human-centered documentation and decision-making, as illustrated in Figure 2.

Task 3: Laboratory and field testing

The developed AR software and AI algorithms will be tested extensively in both laboratory and field settings. A large-scale girder bridge subassemblage with realistic fatigue and corrosion damage will be established in the structural testing laboratory at the University of Kansas for testing the developed AR inspection tools. In addition, several bridges in the inventory of KDOT and other participating member states will be selected for field testing and validation. The team will work closely with the KDOT inspection crew to ensure the tools are relevant and address practical challenges.

4. Deliverables:

This project will result in user-friendly AR software packages for participating member states empowered by AI algorithms for automated damage detection that can be readily adopted by bridge inspectors to perform AI and AR assisted bridge inspections using both AR headsets and tablet devices. In addition, quarterly reports and a final report will be generated in MS Word format. The team will hold quarterly online report meetings with participating parties during the project. The team also plans to hold on one in-person mid-project participant meeting in Year 3. The team will also disseminate the findings and results from this research through journal and conference publications.

5. Budget and Schedule:

The estimated total project cost is $600,000. The estimated duration is 3 years.

Funding requested: $120,000 ($40,000 per year for three years) from each participating state.

6. Project Personnel:

The proposed research will be carried out by a group of faculty members from the University of Kansas with expertise ranging from bridge structures, structural inspection and assessment, computer vision, artificial intelligence, and augmented reality. **Contact:** Jian Li, Ph.D., P.E. (jianli@ku.edu), University of Kansas, Dept. of Civil, Environ. & Arch. Eng.

References:

Kong, X. and Li, J. (2018). "Vision-based Fatigue Crack Detection of Steel Structures Using Video Feature Tracking." *Computer-Aided Civil and Infrastructure Engineering*, Wiley, 33(9), 783-799.

Li, J., Bennett, C., Collins, W., and Moreu F. (2022). *Fatigue Crack Inspection Using Computer Vision and Augmented Reality*. NCHRP-IDEA Program Project Final Report, NCHRP IDEA Project 223.