Artificial intelligence can identify patterns in surface cracking to assess damage in reinforced concrete structures

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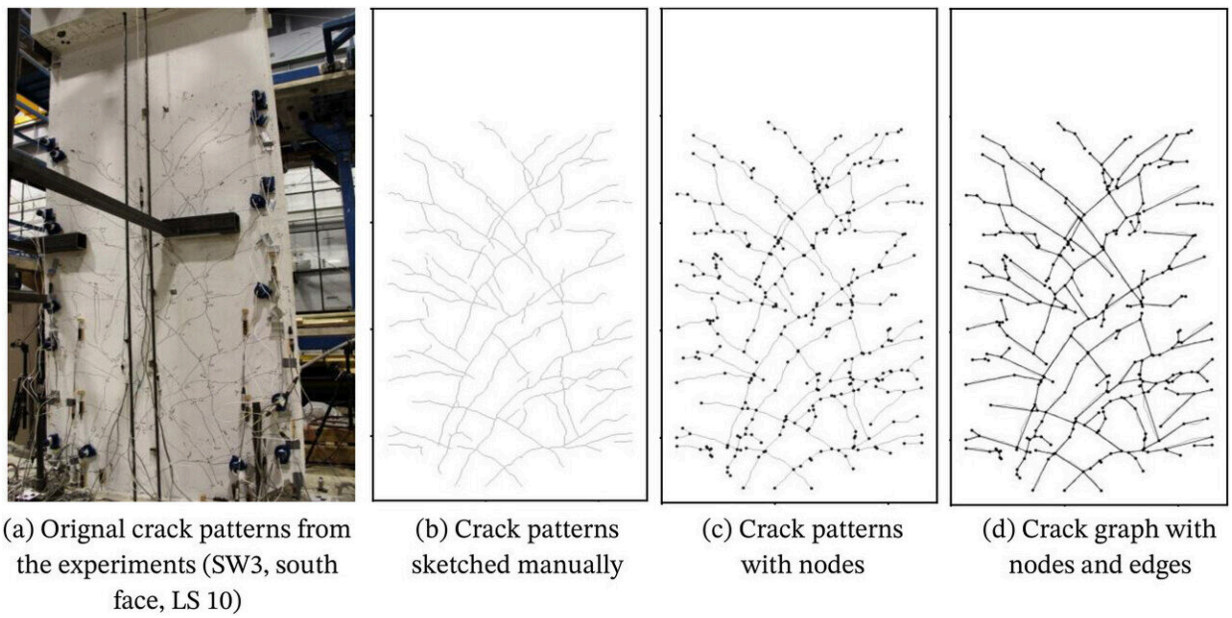

The concept of crack-to-graph conversion using corner detection and pixel tracking algorithm. (a) Original crack patterns from the experiments (b) crack patterns sketched manually; (c) crack patterns with nodes; and (d) crack graph with nodes and edges. Credit: Drexel University

Recent structural collapses, including tragedies in Surfside, Florida, Pittsburgh, and New York City, have centered the need for more frequent and thorough inspections of aging buildings and infrastructure across the country. But inspections are time-consuming, and often inconsistent, processes, heavily dependent on the judgment of inspectors.

Researchers at Drexel University and the State University of New York at Buffalo are trying to make the process more efficient and definitive by using artificial intelligence, combined with a classic mathematical method for quantifying web-like networks, to determine how damaged a concrete structure is, based solely on its pattern of cracking.

In the paper "A graph-based method for quantifying crack patterns on reinforced concrete shear walls," which was recently published in the journal *Computer-Aided Civil and Infrastructure Engineering*, the researchers, led by Arvin Ebrahimkhanlou, Ph.D., an assistant professor in Drexel's College of Engineering, and Pedram Bazrafshan, a doctoral student in the College, present a process that could help the country better understand how many of its hundreds of thousands of aging bridges, levees, roadways and buildings are in urgent need of repair.

"Without an autonomous and objective process for assessing damage to the many reinforced concrete structures that make up our built environment, these tragic structural failures are sure to continue," Ebrahimkhanlou said. "Our aging infrastructures are being used beyond their design lifespan, and because manual inspections are time-consuming and subjective, indications of structural damage may be missed or underestimated."

The current process for inspecting a concrete structure, such as a bridge or a parking deck, involves an inspector visually examining it for cracking, chipping, or water penetration, taking measurements of the cracks, and noting whether or not they have changed in the time between inspections—which may be years. If enough of these conditions are present and appear to be in an advanced state—according to a set of guidelines on a damage index—then the structure could be rated "unsafe."

In addition to the time it takes to go through this process for each inspection, there is widespread concern that the process leaves too much room for subjectivity to skew the final assessment.

"The same crack in a reinforced concrete structure can appear menacing or mundane—depending on who is looking at it," Bazrafshan said. "A crack can be an innocuous part of a building's settling process or a telltale sign of structural damage; unfortunately, there is little agreement on precisely when one has progressed from the former to the latter."

The first step for Bazrafshan and Ebrahimkhanlou's group was to eliminate this uncertainty by creating a method to precisely quantify the extent of cracking. To do it, they employed a mathematical method called graph theory, which is used to measure and study networks—most recently, social networks—by pinpointing its graph features, such as the number of times cracks intersect on average.

Ebrahimkhanlou originally developed the process for using graph features to create a kind of "fingerprint" for each set of cracks in a reinforced concrete structure and—by comparing the prints of newly inspected structures to those of structures with known safety ratings—produce a quick and accurate damage assessment.

"Creating a mathematical representation of cracking patterns is a novel idea and the key contribution of our recent paper," Ebrahimkhanlou said. "We find this to be a highly effective way to quantify changes in the patterns of cracking, which enables us to connect the visual appearance of a crack to the level of structural damage in a way that is quantifiable and can be consistently repeated regardless of who is doing the inspection."

The team used AI pixel-tracking algorithms to convert images of cracks to their corresponding mathematical representation: a graph.

"The crack-to-graph conversion and feature-extraction processes take just a minute or so per image, which is a significant improvement by comparison to the inspection process which could take hours or days to make all of the required measurements," Bazrafshan said. "This is also a promising development for the possibility of automating the entire analysis process in the future."

To develop a feature framework for comparison, they had a machine learning program extract graph features from a set of images of reinforced concrete shear wall structures with different height-to-length ratios, that were created to test different behaviors of the walls that could occur in an earthquake.

Focusing specifically on the group of images that showed moderate cracking—the kind that shows that the safety of the structure is under question—the team trained a second algorithm to correlate the extracted graph features with a tangible scale showing the amount of damage imposed on the structure. For example, the more cracks intersect one another—which corresponds with a higher "average degree" of their graph feature—the more serious the damage to the structure.

The program assigned a weighted value to each of these features, depending on how closely they correlated with mechanical indicators of damage, to produce a quantitative profile against which the algorithm could measure new samples to determine the extent of their structural damage.

To test the assessment algorithm, the team used images of three large-scale walls that had been mechanically tested in a lab at the University at Buffalo to determine their conditions. The team used images of one side of each wall as a training set and then tested the model with images of the opposite side to test its ability to predict each sample's level of damage.

In each case, the AI program was able to correctly assess the damage with greater than 90% accuracy, indicating that the program would be a highly effective means of rapid damage assessment.

"This is just the first step in creating a very powerful assessment tool that leverages volumes of research and human knowledge to make faster and more accurate assessments of structures in the built environment," Ebrahimkhanlou said. "Imposing order on a seemingly chaotic set of features is the essence of scientific discovery. We believe this innovation could go a long way toward identifying problems before they happen and making our infrastructures safer."

The group plans to continue its work by training and testing the program against larger and more diverse datasets, including other types of structures. And they are also working toward automating the process so that it could be integrated into structural monitoring systems, as well as the process of collecting photos and video of damaged structures following earthquakes and other natural disasters.

More information: Pedram Bazrafshan et al, A graph-based method for quantifying crack patterns on reinforced concrete shear walls, *Computer-Aided Civil and Infrastructure Engineering* (2023). DOI: 10.1111/mice.13009

Provided by Drexel University

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