An Integrated Computer Vision Framework for Structural Defect Identification, Quantification, and Multi-Parameter Severity Assessment in Reinforced Concrete Beams

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Current computer vision applications in Structural Health Monitoring (SHM) predominantly focus on binary crack detection, offering limited support for engineering condition assessment, prioritization of repairs, and maintenance decision-making. Existing studies have demonstrated reliable crack quantification; however, multi-parameter severity assessment frameworks that convert measured crack characteristics into actionable condition ratings remain comparatively underexplored. To address this gap, this study developed a comprehensive image-based framework integrating automated structural defect identification and precise geometric quantification directly with a robust severity assessment model tailored for Reinforced Concrete (RC) beams. A benchmark dataset of surface cracks exclusively in RC beams was constructed using images captured under realistic field and laboratory conditions, intentionally including varying illumination, texture, shadows, staining, and surface deterioration commonly encountered during inspections. A total of 300 high-resolution images were collected, with 100 images manually annotated for semantic segmentation. The dataset was divided into training, validation, and testing subsets of 70%, 20%, and 10%, respectively. The finalized dataset includes precise crack masks and image-derived parameters such as crack width, length, orientation, location, density, and branching characteristics. Semantic segmentation and advanced image-processing techniques were utilized to automatically extract these physical parameters, prioritizing critical serviceability thresholds and the spatial distribution of cracks. Additionally, image preprocessing procedures, including contrast enhancement and noise reduction, were successfully evaluated to improve visibility under challenging conditions. The quantified crack characteristics were subsequently integrated into a novel rule-based severity assessment framework informed by established engineering standards and structural judgement. By evaluating multiple interrelated parameters rather than relying on crack width alone, the framework successfully executed a severity assessment that classified the affected RC beams into Minor, Moderate, and Critical severity levels. Results demonstrated that integrating semantic segmentation with multi-parameter analysis successfully extracted geometric features capable of driving these accurate, standardized severity classifications. Model outputs were thoroughly benchmarked against manual measurements and engineer-assigned condition ratings, confirming high classification reliability. Ultimately, this framework successfully converted visual defect observations into actionable engineering ratings, significantly reducing reliance on subjective manual interpretation while providing a scalable methodology for rapid inspection, maintenance prioritization, and long-term monitoring of ageing RC beam infrastructure.

Keywords: benchmark dataset, computer vision, reinforced concrete cracks, severity assessment, Structural Health Monitoring (SHM)