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Synergizing Computer Vision and Multi-Objective Optimization in IoT for Structural Health Monitoring: A Study Inspired by Indian Surrealism

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Abstract

Structural health monitoring (SHM) supports the assessment of bridges, buildings, dams, and other infrastructure by identifying damage and changes in structural behaviour. Internet of Things (IoT) networks enable continuous data collection, while computer vision (CV) methods analyse images to detect cracks, corrosion, deformation, and related anomalies. However, practical SHM systems must balance detection accuracy with computational cost, latency, bandwidth, and energy use. This review paper examines how CV and multi-objective optimization (MOO) can be integrated into IoT-based SHM and considers Indian surrealism as a conceptual source of ideas for image interpretation and visualization. The reviewed literature describes image segmentation, edge detection, convolutional neural networks, Pareto-based optimization, and evolutionary algorithms as relevant technical approaches. The paper then discusses whether surrealist concepts such as juxtaposition, displacement, ambiguity, and unexpected relationships could inspire exploratory feature analysis or alternative visual representations of structural anomalies. These artistic concepts are not established engineering algorithms, and their value for SHM remains a hypothesis requiring empirical evaluation. A conceptual framework is therefore outlined in which conventional CV models identify candidate anomalies, MOO balances performance and resource constraints, and surrealism-inspired transformations are tested only as supplementary analytical tools. The paper identifies key challenges, including reproducibility, interpretability, data quality, and the need to avoid confusing artistic distortion with actual damage. It concludes that the interdisciplinary idea is promising as a research direction, but claims of improved detection must be demonstrated through controlled experiments, benchmark datasets, and comparisons with established methods.

Keywords: computer vision; structural health monitoring; multi-objective optimization; Internet of Things; Indian surrealism; image segmentation; infrastructure monitoring

1. Introduction

1.1 Background and Motivation

Structural health monitoring (SHM) is used to assess the condition of infrastructure such as bridges, buildings, and dams. Traditional inspection often relies on human observation and contact-based sensors that measure properties such as strain, vibration, displacement, and temperature. These methods remain important, but they can be costly, time-consuming, and difficult to scale across large or inaccessible structures. Computer vision (CV), supported by

cameras and drones, offers a non-contact means of identifying visible defects from images and video. When connected to Internet of Things (IoT) networks, visual data can be combined with measurements from distributed sensors to support more continuous monitoring (Jiang & Adeli, 2018; Xu et al., 2019; Yang et al., 2019).

1.2 Problem Statement

A practical SHM system must balance several competing objectives. High detection accuracy may require larger models and greater computational resources, whereas IoT devices often have limited processing power, bandwidth, and energy. Environmental conditions—including shadows, changing illumination, weather, occlusion, and surface variation—can also reduce image quality and complicate defect detection. Single-objective optimization does not adequately represent these competing requirements. Multi-objective optimization (MOO) can help identify alternative solutions and make trade-offs explicit (Chakraborty & Roy, 2021; Li et al., 2020).

1.3 Aim and Scope

This review examines the integration of computer vision and MOO in IoT-based SHM and explores Indian surrealism as a conceptual lens for investigating image perception, irregularity, and visualization. Its objectives are to summarize relevant SHM and optimization approaches; describe possible links between surrealist concepts and image analysis; propose a conceptual workflow for future testing; and identify limitations and research priorities. The paper is a conceptual review, not an experimental validation study. No new dataset, implemented algorithm, or measured performance result is claimed.

1.4 Review Approach and Analytical Boundaries

The manuscript uses a narrative, concept-led review of the sources already cited in the paper. It brings together three strands: technical work on CV and SHM, research on optimization in IoT environments, and art-historical or psychoanalytic discussions of surrealism. These strands are considered for their relevance to a proposed interdisciplinary framework rather than treated as evidence of a single tested system. The references listed at the end are retained from the supplied manuscript; their bibliographic details have not been independently verified in this revision. Consequently, the paper does not claim a systematic database search, exhaustive coverage of the field, or a quantitative synthesis of published results.

2. Literature Review

2.1 Computer Vision in Structural Health Monitoring

CV enables the analysis of images captured by fixed cameras, mobile devices, or drones. Common tasks include image enhancement, segmentation, edge detection, feature extraction, and classification. These techniques can help locate cracks, corrosion, surface deterioration, and deformation without direct contact with the structure (Zhu et al., 2018). Convolutional neural networks (CNNs) learn visual features from labelled examples and have been applied to defect classification and detection. Their performance, however, depends on representative training

data, appropriate validation, and robustness to differences in lighting, camera angle, distance, and material texture (Yang et al., 2019).

2.2 IoT-Based Monitoring

IoT architectures connect distributed sensors and imaging devices so that structural data can be collected over time and transmitted for analysis. Sensors may measure strain, acceleration, displacement, or temperature, while cameras provide complementary visual evidence. Such integration can improve coverage and support timely alerts, particularly for structures that are difficult to inspect manually. Nevertheless, network reliability, data volume, device energy consumption, communication latency, and data synchronization remain practical concerns (Xu et al., 2019). A useful SHM architecture must therefore consider not only whether a defect can be detected, but also where and when processing should occur.

2.3 Multi-Objective Optimization

MOO addresses problems in which several objectives must be considered simultaneously. In SHM, objectives may include maximizing detection accuracy and fault sensitivity while minimizing latency, energy consumption, communication cost, and computational complexity. These goals can conflict: a larger model may improve classification but consume more power or take longer to run. Pareto-based methods identify solutions for which one objective cannot be improved without worsening at least one other objective. This allows engineers to select a suitable compromise for the specific infrastructure and deployment conditions (Li et al., 2020; Zhang et al., 2019). Genetic algorithms and particle swarm optimization are among the evolutionary approaches that can be used to explore complex search spaces, including sensor placement and resource allocation.

2.4 Surrealism, Psychoanalysis, and Indian Art

Surrealism is commonly associated with dream imagery, unexpected juxtapositions, displacement, and departures from ordinary visual logic. Psychoanalytic writing, including Freud's work, has influenced interpretations of images as more than straightforward depictions of visible reality (Freud, 1930; Matthews, 2018). Discussions of Indian surrealism connect such approaches with local cultural, philosophical, symbolic, and mythological contexts. The source literature cited in this manuscript discusses artists including Gaganendranath Tagore and Anish Kapoor in relation to abstraction, perception, and the relationship between familiar forms and unfamiliar contexts (Kapoor, 2017; Mukherjee, 2018; Sharma, 2019). These artistic ideas can inform questions about how observers interpret visual anomalies, but they should not be treated as evidence that an engineering model will perform better.

2.5 Interdisciplinary Connection

The potential connection between art and CV is methodological rather than literal. Surrealist practices may prompt researchers to question assumptions about normal patterns, boundaries, context, and visual salience. For example, unusual combinations of features could encourage the

investigation of weak or unexpected signals in images. Yet deliberately altered or abstracted images can also introduce misleading patterns. Any art-inspired operation must therefore be defined precisely, applied transparently, and evaluated against unmodified data and conventional baselines.

3. Conceptual Methodology

3.1 Proposed IoT-Based SHM Workflow

The proposed framework is conceptual and is intended to guide future empirical work. First, cameras, drones, and structural sensors acquire visual and physical measurements. Second, a preprocessing stage checks image quality, aligns data where necessary, and records relevant capture conditions. Third, established CV methods—such as segmentation, edge detection, or CNN-based classification—identify candidate anomalies. Fourth, MOO selects or configures a model and processing strategy according to accuracy, latency, energy, and computational constraints. Finally, results are presented to an engineer for review, with alerts linked to the underlying image and sensor evidence. Human verification remains important, especially where a false negative could affect public safety.

In a practical deployment, each stage should retain an auditable link between the original observation and the system output. An alert should identify the image or sensor record that triggered it, indicate model confidence or uncertainty, and distinguish automated screening from a confirmed engineering diagnosis. Where network capacity is limited, preliminary screening may occur on the device, with higher-cost analysis reserved for uncertain or high-priority cases. Such a staged arrangement is a design option to investigate, not a performance result established by this review.

3.2 Where Surrealism-Inspired Ideas Could Be Tested

Rather than inserting subjective artistic rules directly into a safety-critical algorithm, future research could operationalize a small number of ideas as testable transformations or analysis prompts. Juxtaposition might motivate comparison of neighbouring regions or sensor channels; displacement might motivate analysis of deviations from a structural baseline; and ambiguity might motivate uncertainty estimation or review of low-confidence detections. These are proposed analogies, not established mappings between art concepts and engineering functions. Each transformation would need a formal definition and a clear rationale before implementation.

3.3 Multi-Objective Formulation

A generic optimization problem can be expressed as the simultaneous minimization of computational cost, latency, and energy use while maximizing detection performance. In practice, objectives may be written in a common minimization form, for example: minimize f1 = 1 − detection score, f2 = inference time, and f3 = energy consumed per analysis. Constraints may specify a minimum acceptable recall, a maximum response time, and the available device budget. The precise metrics and thresholds must be selected for the application and validated

with domain experts. A Pareto front can then present alternative configurations without implying that one solution is universally best.

3.4 Evaluation Plan

A future experiment should compare a conventional CV baseline with models that include explicitly defined surrealism-inspired operations. The same training, validation, and test splits should be used for fair comparison, with separate evaluation under different lighting, surface conditions, camera angles, and defect sizes. Relevant outcomes include precision, recall, F1 score, false-alarm rate, inference time, memory use, and energy consumption. Ablation tests should determine whether each added operation contributes measurable value. Independent test data and reproducible implementation details are necessary to avoid overstating performance.

4. Potential Applications and Discussion

4.1 Bridges, Buildings, and Dams

For bridges and tall buildings, drone imagery can provide access to difficult-to-reach surfaces. CV can screen images for cracks or corrosion, while MOO can help choose an appropriate balance between coverage, processing time, and battery use. A surrealism-inspired approach could be evaluated as an auxiliary method for highlighting irregular shapes or comparing unexpected local patterns. It must not replace engineering inspection or be assumed to detect defects more accurately without testing.

4.2 Historic and Culturally Significant Structures

Historic structures present a particular challenge because age-related surface variation, weathering, ornament, and repairs can resemble damage. A monitoring system must distinguish meaningful deterioration from expected material and decorative features. Cultural and art-historical knowledge may help researchers formulate context-aware questions, but the algorithm must be trained and evaluated using appropriate structural evidence. Any visual transformation should preserve traceability to the original image so that engineers can inspect the actual surface condition.

4.3 Visualization and Decision Support

MOO can produce multiple non-dominated configurations, and clear visualization can help engineers understand trade-offs between accuracy, response time, and energy consumption. Surrealist approaches to juxtaposition or altered perspective may inspire exploratory visual interfaces, but operational dashboards should remain clear, interpretable, and faithful to measured data. Artistic presentation should never obscure uncertainty, exaggerate a suspected defect, or confuse a visualization with direct evidence.

4.4 Technical and Ethical Limitations

The principal challenge is operationalizing abstract artistic concepts in reproducible terms. If transformations are subjective, results may be difficult to repeat or compare. Artificially distorted

imagery may also create false anomalies or suppress genuine damage. Dataset bias, limited examples of rare defects, and differences between laboratory and field conditions can further reduce reliability. For safety-critical applications, the proposed approach requires transparent documentation, uncertainty reporting, independent validation, and human oversight. Claims about improved accuracy, efficiency, or adaptability remain provisional until supported by experiments.

5. Challenges and Future Research

5.1 Technical Challenges

Researchers must define the proposed operations mathematically, determine whether they add information beyond standard augmentation or feature analysis, and ensure that they do not damage relevant visual evidence. Computational overhead should be measured because additional processing could conflict with the resource constraints that motivate MOO. Data governance, camera calibration, synchronization with sensor measurements, and performance under changing environmental conditions also require attention.

5.2 Future Research Directions

Future work should begin with a small, reproducible pilot study using public or appropriately documented SHM image datasets. Researchers should pre-register or clearly state hypotheses, publish the transformation rules, compare against strong baselines, and report negative as well as positive results. Further work could test transferability across concrete, steel, masonry, and historic materials; evaluate edge- and device-level deployment; and consult structural engineers and art historians when defining culturally informed visual categories. The most useful outcome may be a rigorous method for testing interdisciplinary ideas rather than an assumption that artistic inspiration inherently improves engineering.

6. Conclusion

This review has considered how CV and MOO can support IoT-based SHM and how ideas associated with Indian surrealism might inspire exploratory approaches to visual analysis and decision support. CV offers tools for identifying visible defects, while MOO makes trade-offs among detection performance, latency, computational load, and energy explicit. Concepts such as juxtaposition, displacement, and ambiguity may provide prompts for future experiments, but they are not validated algorithms in themselves. The central contribution is a conceptual framework and evaluation plan, not a claim of measured improvement.

Future studies should test the proposed ideas using controlled comparisons, transparent metrics, independent datasets, and expert review. The safety and interpretability of SHM must remain primary. Interdisciplinary collaboration may be valuable when it produces precise, reproducible research questions and demonstrable benefits. Until those benefits are established empirically, surrealism-inspired methods should be regarded as supplementary research hypotheses rather than replacements for validated monitoring techniques.

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