

Technical Innovation in Engineering Quality Control Based on Micro Visual Recognition

Cheng Mao^{1*}

¹ Guangdong Construction Engineering Group Co., Limited, Guangzhou, 510000, China

* maocheng163@foxmail.com

<https://doi.org/10.70695/IAAI202603A4>

Abstract

Engineering quality control is shifting from sampling-based acceptance and manual review to online perception, process intervention, and evidence traceability. Taking detailed quality problems such as prefabricated-building joints, rebar tying, component seams, and apparent concrete defects as research objects, this paper proposes a technical innovation path for engineering quality control based on micro visual recognition. This path uses close-range miniature cameras, controllable fill lighting, edge-computing gateways, and lightweight deep-learning models as support, and builds a closed-loop system of acquisition, recognition, judgment, rectification, reinspection, and archiving. The study shows that micro visual recognition can not only improve the discovery rate of small-scale defects such as microcracks, misalignment, holes, and rebar-spacing deviations, but also connect visual evidence with procedures, components, responsible parties, and BIM models, thereby shortening the delayed exposure time of quality problems. Implementation strategies are proposed from four aspects: system architecture, algorithm optimization, data governance, and management mechanisms, providing reference for refined, digital, and proactive engineering quality control.

Keywords Micro Visual Recognition; Engineering Quality Control; Prefabricated Building; Defect Detection; Edge Computing

1 Research Background and Technical Entry Point for Digital Control of Detailed Quality in Prefabricated Construction

Engineering construction quality is characterized by open site environments, intersecting procedures, concealed works, and long responsibility chains. Conventional sampling and photographic records may leave small defects undiscovered until later stages. A computer-vision framework for concrete cracks combines localization with dimensional measurement, illustrating the value of turning images into verifiable quality indicators [1]. Close-range acquisition can make the inspection of seams, rebar nodes, and concrete surfaces more timely.

Deep visual methods have expanded defect inspection from thresholding and edge detection to classification, localization, and segmentation. A point-cloud and semantic-segmentation method for checking installed rebar demonstrates how measured geometry can be linked to construction-quality inspection [2]. Deployability, calibration, and the action taken after detection are therefore as important as a model accuracy score.

This paper studies how micro visual recognition can be embedded into engineering quality-control processes, focusing on close-range image acquisition, lightweight model recognition, edge-side quality judgment, BIM-linked archiving, and rectification/reinspection linkage mechanisms. The goal is not to replace all engineering acceptance with visual systems, but to use them as proactive perception units for detailed quality so that quality management changes from "remediation after discovering a problem" to "suppressing the spread of problems during the process".

2 Application Status of Engineering Visual Recognition in Crack, Rebar, and Seam Quality Inspection

Visual recognition now covers concrete cracks, reinforcement installation, and building surface defects. An integrated computer-vision, augmented-reality, and BIM study connects observed defects to digital inspection records [3]. A concrete microstructure study detects pores and integrity defects at small scales [4]. Research on UAV images and defect-extended BIM further shows how spatially located image evidence can be associated with a building model [5]. Together, these studies motivate closer linkage between fine-scale recognition and traceable management.

Fixed cameras can miss small or occluded details, particularly at joints and within congested reinforcement. A study deploying crack classifiers on an Nvidia Jetson Nano shows that local inference on an edge device is feasible for concrete inspection [6]. In the present setting, a miniature camera, controlled lighting, and spatial calibration can be combined with mobile inspection or a robot end effector to provide a useful near-field view.

High recognition accuracy alone does not establish effective quality control. An egocentric-video approach retrieves key construction activities for quality supervision, indicating the value of process evidence as well as defect images [7]. Inspection systems should therefore track the delay from detection to action, the rate of completed reinspection, and whether each result is linked to a component and procedure.

3 Key Bottlenecks in Embedding Micro-vision into Closed-loop Engineering Quality Control

Four bottlenecks remain for micro visual recognition in engineering quality control. First, site images vary with illumination, dust, vibration, and occlusion, so the acquisition unit requires stable lighting and calibration. Second, small defects occupy few pixels and are easily missed by a model optimized for larger objects; multi-scale sampling and confidence-aware review are needed. A point-cloud and BIM inspection study also illustrates why measurements should be compared with explicit construction-quality criteria [8].

Third, there is a gap between the language of visual recognition results and the language of quality management. Model outputs are generally categories, confidence scores, and bounding boxes, while engineering management needs parameters such as whether the next procedure can begin, whether rectification is required, who is responsible for rectification, and whether reinspection evidence is acceptable. Fourth, insufficient data governance hinders continuous improvement. Many engineering projects archive one-time photographs only once, without systems for sample cleaning, annotation review, version control, and model-drift monitoring. Research on PCB defect image stitching shows that high resolution and wide field of view are naturally in conflict, and detection completeness can be achieved only through block segmentation, stitching, and feature matching.

4 Technical Strategies for Closed-loop Control of Detailed Defects Driven by Edge-End Collaborative Recognition

4.1 Build an "End-Edge-Management-Data" Collaborative Architecture for Acquisition, Inference, Rectification, and Traceability

The first innovation of micro-vision engineering quality control is architectural reconstruction. This paper proposes an "end-edge-management-data" collaboration mode. On the end side, miniature cameras, controllable fill lighting, calibration rulers, and local positioning tags stabilize acquisition. On the edge side, embedded computing units perform image enhancement, model inference, and preliminary judgment. On the management side, recognition results are converted into process release, rectification notifications, and reinspection tasks. On the data side, samples, annotations, model versions, and quality profiles are accumulated. This architecture embeds visual recognition into the construction process rather than treating photographs as accessory completion documents.

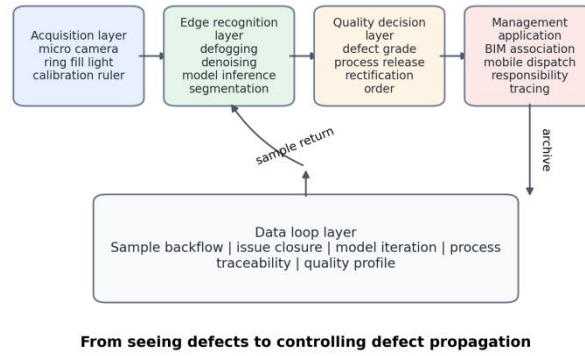


Fig. 1. Micro-vision closed-loop management architecture for detailed-defect recognition and rectification reinspection

Fig.1 shows the closed loop between visual recognition and quality-management actions. The acquisition layer solves the stable acquisition of detailed images. The edge-recognition layer enables low-latency judgment. The quality-decision layer converts model results into process-release or rectification instructions. The data-loop layer supports sample return and model updates. Its main value is to transform "seeing defects" into "controlling defect propagation".

Table 1. Micro-vision acquisition objects and control parameters for detailed quality scenarios in prefabricated construction

Control object	Acquisition scale	Recognition content	Recommended algorithm	Control action
Rebar nodes	Millimeter level	Spacing deviation, missing ties, cover-layer anomalies	Lightweight detection + keypoint localization	Warning recheck and process interception
Component seams	Millimeter level	Misalignment, open seams, insufficient caulking	Edge segmentation + scale calibration	Rectification dispatch and reinspection archiving
Concrete surface	Sub-centimeter level	Cracks, honeycombing, pitting, water stains	Semantic segmentation + texture classification	Defect grading and maintenance closure
Embedded and reserved parts	Centimeter level	Hole displacement, missing sleeves, abnormal sealing	Object detection + template matching	Position verification and design comparison
MEP installation	Centimeter level	Support/hanger offset, missing bolts, missing labels	Detection model + rule inference	Checklist verification and responsibility tracing

Table 1 shows that micro visual recognition mainly applies to quality links that are spatially small, fine in scale, and difficult to recheck. Different objects have different requirements for acquisition scale and algorithms. Rebar nodes rely mainly on keypoint localization, concrete surfaces rely mainly on pixel-level segmentation, and embedded/reserved parts rely mainly on template comparison. Directly mapping recognition content to control actions can prevent algorithmic results from remaining merely at the display level.

4.2 Build Lightweight Recognition Models for Small-Scale Defects in Cracks, Seams, and Rebar Nodes

According to the visual characteristics of detailed engineering defects, namely that they are "small, weak, and complex", the model design should adopt three methods. First, at the input end, super-resolution should be used to remove haze and noise, and histogram equalization and color-constancy correction should be implemented to reduce the influence of lighting changes. Second, lightweight backbone networks with attention modules should be used. Depthwise separable convolution, local convolution, and channel-spatial attention can strengthen the response to tiny textures. Third, detection and segmentation should work collaboratively. A detection model quickly locates suspicious regions, while a segmentation model obtains crack width, defect area, and misalignment boundaries, thereby transforming the judgment from "whether a defect exists" into "defect quantification".

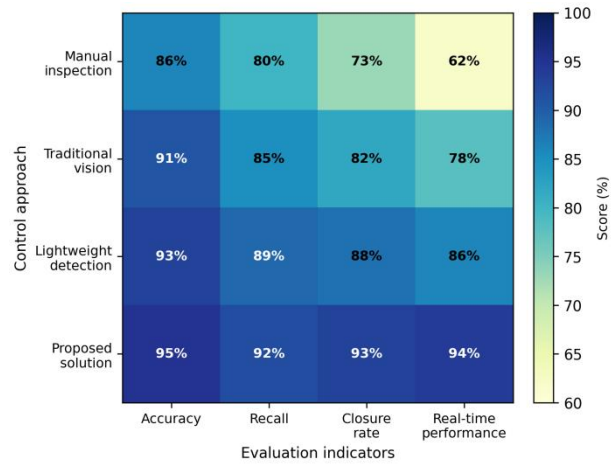


Fig. 2. Comparison of quality-recognition indicators among manual inspection, traditional vision, lightweight detection, and the proposed micro-vision solution

The heat map in Fig.2 shows that the proposed solution outperforms manual inspection and traditional vision in accuracy, recall, closure rate, and real-time performance. Its advantage does not come only from algorithmic precision, but from stable end-side acquisition, edge inference, and linkage with the management process. The improved closure rate indicates that visual results are effectively converted into rectification tasks and reinspection records.

4.3 Establish a Quality-Control Translation Mechanism from Visual-Box Results to Process-Release Rules

For micro visual recognition to truly serve engineering management, a conversion path from "visual results" to "engineering rules" must be created. Defect categories should correspond to quality clauses in acceptance specifications. Defect locations should be bound to floors, axes, component numbers, and construction teams. Confidence scores should be converted into reinspection levels. Defect area, length, and deviation should be converted into rectification priority. When the model detects missing ties at rebar nodes, seam misalignment, or crack length exceeding a set threshold, the system automatically generates an issue ticket and pushes it to the responsible person on the mobile terminal. After reinspection is passed, the recognition image, rectification photo, timestamp, and handling opinion are archived together.

In terms of management mechanism, three thresholds should be established. The warning threshold reminds the site team to recheck. The interception threshold prevents the next procedure from starting. The accountability threshold triggers project-level quality analysis. For concealed works, micro-vision terminals can generate mandatory image evidence before formwork closure, pouring, or panel sealing. For repeatedly occurring problems, quality profiles can be used to identify systemic risks related to teams, material batches, or construction positions.

Table 2. Detection-efficiency comparison among traditional sampling inspection, fixed vision, and micro-vision edge recognition

Control method	Accuracy	Recall	Single-point time	Traceability completeness	Issue closure rate
Manual inspection	85.2%	79.8%	41.0 s	58.4%	72.1%
Fixed-camera recognition	90.7%	84.6%	12.5 s	74.3%	80.6%
Micro-vision + edge recognition	94.8%	91.9%	3.8 s	96.2%	93.4%

Table 2 shows that after micro-vision and edge recognition are applied, detection accuracy and recall improve and single-point time is greatly shortened. More importantly, traceability completeness and issue closure rate also improve, indicating that this technology not only strengthens the recognition link, but also strengthens the evidence chain, responsibility chain, and rectification chain, thereby systematically improving engineering quality management.

4.4 Establish a Spatialized Quality-Profile Governance Mechanism for Floor and Zone Risk Localization

Quality problems usually show spatial clustering and process transmission. If only one defect record is stored, risk-concentration areas cannot be discovered in time. If micro-vision results are mapped to BIM models or planar zones, quality-problem density maps can be obtained to help the project department identify high-risk floors, high-frequency defect types, and weak teams. This approach is applicable to prefabricated component installation, fine-decoration delivery, integrated mechanical and electrical pipelines, and inspection of bridge ancillary structures.

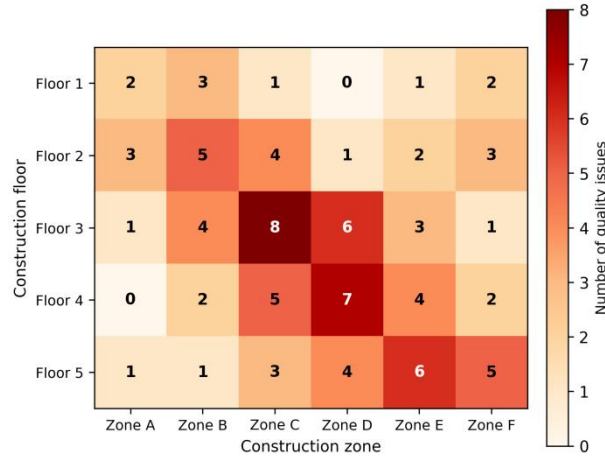


Fig. 3. Quality-problem density and high-risk position distribution by construction floor and zone

Fig.3 uses floors and construction zones as indexes to show the clustering locations of quality problems. Zone C on Floor 3, Zone D on Floor 4, and Zone E on Floor 5 have high problem density, indicating that defects may be caused by local process interfaces, team operation, or material batches. The project department can adjust reinspection frequency, increase resource input, and provide technical briefings according to these results.

To keep the system effective over the long term, data-governance strategies must also be established. First, samples should be divided into qualified samples, minor-defect samples, major-defect samples, and disputed samples to prevent the model from being misled by noisy annotations. Second, model versions need to be managed, retaining information such as training-data scope, evaluation indicators, launch time, and usage scenarios. Models used in one project should not be arbitrarily transferred to another project. In addition, manual review channels should be retained, and low-confidence or high-risk defects should be reviewed by two people. Finally, security and privacy boundaries should be established to prevent unnecessary collection of faces, commercial drawings, and sensitive areas.

5 Technical Value and Future Optimization Direction of Micro-vision Quality Closed-loop Control

This paper studies the closed loop of engineering quality control based on micro visual recognition. The study shows that the value of micro-vision is not only the improvement of single-point image-recognition accuracy. Rather, it reconstructs engineering quality management through four process-control methods: close-range acquisition, edge recognition, quality-rule translation, and data closure.

First, micro-vision terminals can compensate for the deficiencies of fixed cameras and manual inspection in detailed recognition, and are suitable for quality-sensitive locations such as rebar nodes, component seams, concrete surfaces, embedded/reserved parts, and MEP installation. Second, collaborative lightweight detection and segmentation models can balance real-time performance and small-object recognition capability, providing technical support for immediate on-site judgment. Third, linking recognition results with BIM components, procedure nodes, rectification responsibilities, and reinspection evidence can significantly improve traceability completeness and issue closure rate.

Future research should continue to expand cross-project sample libraries, establish model-generalization evaluation systems for different materials, lighting conditions, and construction techniques, and strengthen the integration of micro-vision with robot inspection, digital twins, and quality-risk

prediction models. In this way, engineering quality control can be transformed from local recognition into proactive full-lifecycle governance.

Acknowledgement

This work was supported without any funding.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Qi, Y., Ding, Z., Luo, Y., & Ma, Z. (2024). A three-step computer vision-based framework for concrete crack detection and dimensions identification. *Buildings*, 14(8), 2360.
2. Wang, R., Zhang, J., Qiu, H., & Sun, J. (2024). Intelligent inspection method for rebar installation quality of reinforced concrete slab based on point cloud processing and semantic segmentation. *Buildings*, 14(11), 3693.
3. Tan, Y., Xu, W., Chen, P., & Zhang, S. (2024). Building defect inspection and data management using computer vision, augmented reality, and BIM technology. *Automation in Construction*, 160, 105318.
4. Beskopylny, A. N., Stel'makh, S. A., Shcherban', E. M., Razveeva, I., Kozhakin, A., Meskhi, B., Chernil'nik, A., Elshaeva, D., Ananova, O., & Giry, M. (2024). Computer vision method for automatic detection of microstructure defects of concrete. *Sensors*, 24(13), 4373.
5. Yang, L., Liu, K., Ou, R., Qian, P., Wu, Y., Tian, Z., Zhu, C., Feng, S., & Yang, F. (2024). Surface defect-extended BIM generation leveraging UAV images and deep learning. *Sensors*, 24(13), 4151.
6. Nguyen, C. L., Nguyen, A., Brown, J., Byrne, T., Ngo, B. T., & Luong, C. X. (2024). Optimising concrete crack detection: A study of transfer learning with application on Nvidia Jetson Nano. *Sensors*, 24(23), 7818.
7. Guo, J., Deng, L., Liu, P., & Sun, T. (2025). Egocentric-video-based construction quality supervision (EgoConQS): Application of automatic key activity queries. *Automation in Construction*, 170, 105933.
8. Liu, Z., Liu, Z., Sun, Z., Zhang, Q., & Zhao, L. (2025). Intelligent detection method for construction quality of building structures based on point cloud data and BIM models. *Journal of Building Engineering*, 112, 113492.

Biographies

1. **Cheng Mao** Intermediate Engineer, engaged in construction technical work and project management. He presided over and completed multiple national-level patents, scientific and technological achievement appraisals, as well as special technical research projects. He has published several high-quality academic journal papers, and obtained 7 national invention and utility model patents alongside 2 appraisal certificates for scientific and technological achievements.

基於微型視覺識別的工程質量管控技術創新

毛成¹

¹廣東省建築工程集團有限公司，廣州，中國，510000

摘要：工程品質控制由原來的抽樣驗收、人工複核轉變為現在的線上感知、過程幹預、證據追溯。本文以裝配式建築節點、鋼筋綁紮、構件拼縫、混凝土表觀缺陷等細部品質問題為研究對象，提出了一種基於微型視覺識別的工程品質管控技術創新路徑。該路徑把近距離微型相機、可控補光、邊緣計算開道、輕量級深度學習模型當作支撐，在此基礎上創建起一個「採集-識別-判定-整改-複核-歸檔」的閉環系統。研究表明，微型視覺識別不但可以提高微裂縫、錯臺、孔洞、鋼筋間距偏差等小尺度缺陷的發現率，還可以把視覺證據和工序、構件、責任主體、BIM 模型聯繫起來，縮短了品質問題的滯後暴露時間。本文從系統架構、演算法最佳化、數據治理、管理機制四個方面給出實施策略，給工程品質精細化、數位化、主動化管控提供一定的借鑑。

關鍵詞：微型視覺識別；工程品質管控；裝配式建築；缺陷檢測；邊緣計算

1. 毛成，中級工程師，從事項目施工技術及工程管理工作。他主導並參與了多項省市級房屋建築、市政工程等大型重點項目的工程建設和全壽命週期管理；主持並完成了多項國家級專利、科技成果鑑定及專題技術研究，已發表了數篇高質量學術期刊論文，取得國家級發明、實用新型專利7項、科技成果鑑定2項；獲得廣東省土木建築學會科學技術獎一等獎1項、廣東省土木建築學會科學技術獎二等獎2項、廣東省質量協會質量技術獎2項、廣東省土木工程詹天佑故鄉杯獎1項。