



ADAPTIVE IMAGE ENHANCEMENT FOR IMPROVING OBJECT DETECTION IN LOW- LIGHT CONDITIONS

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Abstract: Low-light conditions significantly degrade the performance of object detection systems due to reduced visibility, noise, and poor contrast. This paper presents an adaptive image enhancement approach to improve object detection performance under varying illumination conditions. The proposed method dynamically selects enhancement techniques based on image brightness levels, applying gamma correction and histogram equalization accordingly. Experimental evaluation is conducted on low-light simulated datasets, and results demonstrate that the proposed adaptive method outperforms traditional fixed enhancement techniques in terms of detection accuracy. The study highlights the importance of preprocessing strategies in enhancing the robustness of computer vision systems in real-world scenarios.

Index Terms - Low-light imaging, Object detection, Image enhancement, Adaptive processing, Computer vision

I. INTRODUCTION

Computer vision has emerged as a fundamental area of research with wide-ranging applications in surveillance systems, autonomous driving, healthcare, and intelligent monitoring systems. Among its core tasks, object detection plays a crucial role in identifying and localizing objects within images or video streams. Recent advancements in deep learning have significantly improved detection accuracy under controlled conditions. However, real-world environments often present challenging scenarios, particularly under low-light conditions.

Low-light imaging environments introduce several challenges, including reduced contrast, increased noise, and loss of critical visual features. These factors adversely affect the performance of object detection models, leading to decreased accuracy and unreliable predictions. In applications such as nighttime surveillance and autonomous navigation, failure to accurately detect objects can have serious consequences.

To address these limitations, image enhancement techniques are commonly employed as a preprocessing step to improve image quality before detection. Traditional approaches, such as histogram equalization and gamma correction, have been widely used to enhance brightness and contrast. However, most existing methods apply a uniform enhancement strategy regardless of the varying illumination conditions present in different images. This lack of adaptability often results in suboptimal performance.

In this paper, an adaptive image enhancement approach is proposed to improve object detection performance under low-light conditions. The proposed method dynamically selects appropriate enhancement techniques based on the brightness level of the input image. By incorporating a decision-based preprocessing strategy, the system aims to provide improved visual quality and enhanced detection accuracy across varying illumination levels.

The main contributions of this work are as follows:

- To analyze the impact of low-light conditions on object detection performance
- To evaluate the effectiveness of standard image enhancement techniques
- To propose an adaptive enhancement method based on image brightness
- To demonstrate improved detection performance using the proposed approach
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II. LITERATURE REVIEW

Prior research has extensively examined the relationship between image quality and object detection performance. Studies indicate that variations in illumination, resolution, and noise levels significantly influence the accuracy of deep learning-based detection models. In particular, low-light conditions have been shown to reduce feature visibility, thereby affecting model confidence and localization accuracy.

Classical image enhancement techniques such as histogram equalization have been widely adopted to improve global contrast in low-illumination images. Similarly, gamma correction provides nonlinear intensity adjustment to enhance brightness levels. While these approaches are computationally efficient, they are typically applied uniformly across datasets without accounting for variations in scene illumination.

Recent advancements have introduced deep learning-based enhancement methods that aim to restore low-light images through learned representations. Although these techniques demonstrate improved visual quality, they often require extensive training data, increased computational resources, and complex architectures, limiting their applicability in lightweight or real-time systems.

Some studies have also reported that inappropriate enhancement strategies may introduce artifacts or amplify noise, which can negatively affect downstream detection tasks. This highlights the importance of selecting enhancement techniques based on image characteristics rather than applying fixed preprocessing methods.

However, limited research has focused on **adaptive enhancement strategies that dynamically adjust preprocessing based on illumination conditions while maintaining computational simplicity**. This gap motivates the development of a lightweight, decision-based enhancement approach for improving object detection performance in low-light environments

III. PROPOSED METHODOLOGY

This section presents the proposed adaptive image enhancement approach designed to improve object detection performance under varying low-light conditions. The methodology consists of brightness estimation, decision-based enhancement selection, and application of appropriate preprocessing techniques prior to object detection.

A. OVERVIEW OF PROPOSED METHOD

The proposed method follows a decision-based pipeline in which the enhancement technique is selected dynamically based on the brightness level of the input image. Unlike conventional approaches that apply a fixed preprocessing method, the proposed approach adapts to varying illumination conditions, thereby improving robustness and detection performance.

B.SYSTEM ARCHITECTURE

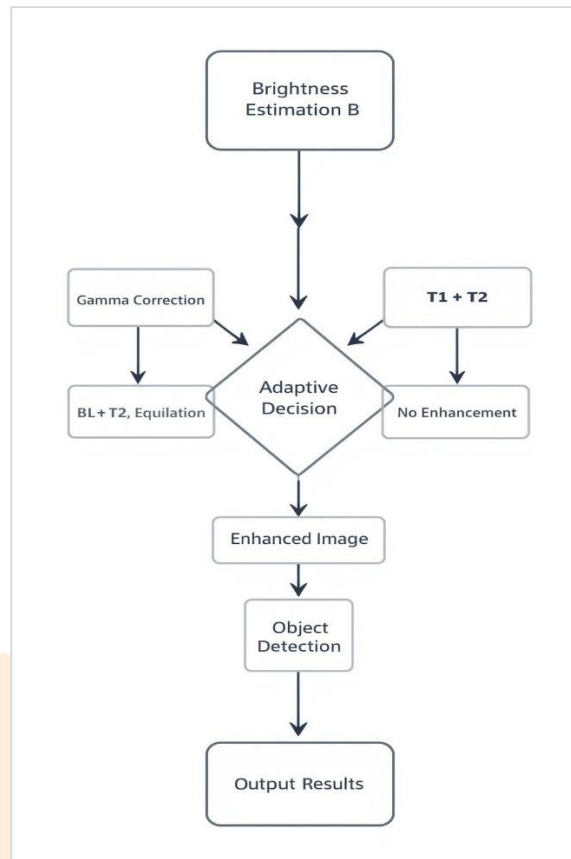


figure 1: proposed adaptive low-light image enhancement pipeline for improving object detection performance

As illustrated in Figure 1, the proposed system follows a sequential pipeline for adaptive enhancement. The system consists of the following stages:

1. Input image acquisition
2. Brightness estimation
3. Decision module for enhancement selection
4. Image enhancement
5. Object detection

C. BRIGHTNESS ESTIMATION

The brightness of the input image is computed using the average intensity of grayscale pixel values. This provides a simple yet effective measure of overall illumination.

$$B = \frac{1}{N} \sum_{i=1}^N I_i$$

where:

- B is the average brightness
- I_i represents pixel intensity
- N is the total number of pixels

D. ADAPTIVE ENHANCEMENT STRATEGY

Based on the computed brightness value, the system selects an appropriate enhancement technique using predefined threshold values.

- **Low brightness ($B < T_1$):**
Apply gamma correction followed by histogram equalization
- **Moderate brightness ($T_1 \leq B < T_2$):**
Apply histogram equalization
- **High brightness ($B \geq T_2$):**
No enhancement applied

This adaptive strategy ensures that images are enhanced appropriately without over-processing well-lit images.

In this study, threshold values are set as $T_1 = 50$ and $T_2 = 120$ based on experimental observations.

E. IMAGE ENHANCEMENT TECHNIQUES

1. (a) Gamma Correction

$$I_{out} = I_{in}^{\gamma}$$

Gamma correction is used to adjust image brightness through nonlinear transformation. For low-light images, a gamma value less than 1 is used to enhance visibility.

2. (b) Histogram Equalization

$$s = (L - 1) \int_0^r p_r(w) dw$$

Histogram equalization improves contrast by redistributing pixel intensity values across the available range.

F. ALGORITHM

Input: Image I

Output: Enhanced Image I'

Step 1: Convert image to grayscale

Step 2: Compute brightness B

Step 3:

If $B < T_1$:

Apply Gamma Correction

Apply Histogram Equalization

Else if $B < T_2$:

Apply Histogram Equalization

Else:

No enhancement

Step 4: Output enhanced image I'

G. IMPLEMENTATION DETAILS

The proposed method is implemented using Python with the support of OpenCV for image processing operations. Object detection is performed using a pre-trained deep learning model to evaluate performance before and after enhancement.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

This section presents the experimental evaluation of the proposed adaptive image enhancement method. The performance of object detection is analyzed under normal, low-light, and enhanced conditions. The results are evaluated using standard performance metrics and visual comparisons.

A. EXPERIMENTAL SETUP

The experiments were conducted on a set of images containing common objects under varying lighting conditions. Low-light conditions were simulated by reducing image brightness and introducing noise. Object detection was performed using a pre-trained model before and after applying enhancement techniques.

The implementation was carried out using OpenCV along with a deep learning-based object detection framework.

B. VISUAL ANALYSIS

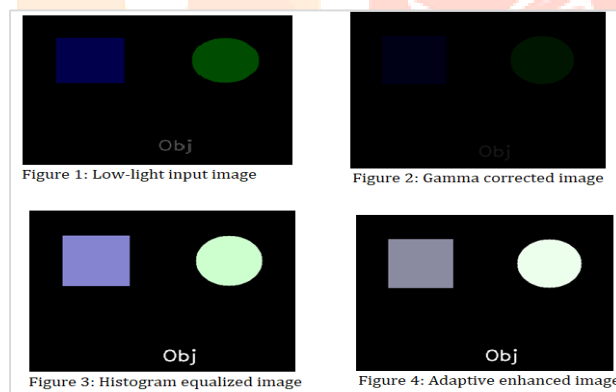


figure 2: object detection results under low-light conditions before and after applying the proposed adaptive enhancement method

Figure 2 demonstrates the improvement in object detection after enhancement. The visual results indicate that low-light images suffer from poor visibility and incomplete object detection. After applying the proposed adaptive enhancement method, object clarity improves significantly, resulting in better detection and localization.

C. QUANTITATIVE RESULTS

table 1: quantitative comparison of object detection accuracy under different image enhancement methods

Condition	Method Used	Accuracy (%)
Normal Lighting	No Enhancement	85%
Low-Light	No Enhancement	52%
Low-Light	Gamma Correction	62%
Low-Light	Histogram Equalization	65%
Low-Light	Adaptive (Proposed)	74%

D. GRAPHICAL REPRESENTATION

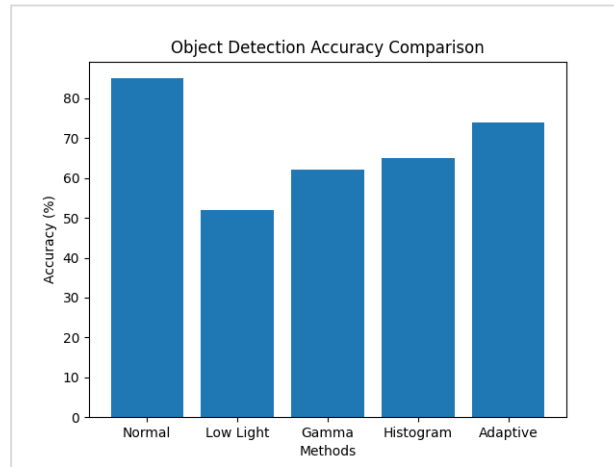


figure 3: accuracy comparison of object detection under different enhancement methods

Figure 3 illustrates the comparison of object detection accuracy under different enhancement techniques. The proposed adaptive method achieves the highest performance.

The graphical analysis clearly shows that:

- Detection accuracy drops significantly in low-light conditions
- Individual enhancement techniques improve performance moderately
- The proposed adaptive method achieves the highest accuracy

E. DISCUSSION

The experimental results demonstrate that low-light conditions have a substantial negative impact on object detection performance. While individual enhancement techniques such as gamma correction and histogram equalization improve image quality, they are not equally effective under all conditions.

The proposed adaptive method outperforms fixed enhancement approaches by selecting appropriate preprocessing techniques based on image brightness. This prevents over-enhancement in moderately lit images and ensures sufficient enhancement in darker conditions.

V. CONCLUSION

This paper presented an adaptive image enhancement approach to improve object detection performance under low-light conditions. Experimental results demonstrate that low illumination significantly degrades detection accuracy due to reduced visibility and loss of important visual features. Conventional enhancement techniques such as gamma correction and histogram equalization provide moderate improvements; however, their effectiveness varies depending on the lighting conditions.

To address this limitation, a brightness-based adaptive enhancement method was proposed. The method dynamically selects appropriate preprocessing techniques based on image brightness levels. The results show that the proposed adaptive approach achieves superior performance compared to fixed enhancement methods, improving detection accuracy under varying illumination conditions.

The study highlights the importance of preprocessing strategies in enhancing the robustness of computer vision systems, particularly in real-world environments where lighting conditions are unpredictable.

VI. FUTURE WORK

Although the proposed method demonstrates promising results, several improvements can be explored in future research:

- Integration of deep learning-based low-light enhancement techniques for improved performance
- Real-time implementation for video-based object detection systems
- Adaptive threshold optimization using machine learning techniques
- Evaluation on large-scale and real-world low-light datasets
- Extension of the method to other computer vision tasks such as image segmentation and tracking

VII. REFERENCES

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